WEIGHT-STRENGTH ANALYSIS OF A MODERN DESTROYER WITH VARYING FRAME SPACINGS

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Thesis
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ABSTRACT

By superimposing two series of grids, one longitudinal and one transverse, on a typical bulkhead-deck arrangement of a destroyer, an analysis of the effect of stiffener spacing on the total weight of structure has been made. Assuming normal design criteria, the weight of longitudinal structure and the weight of transverse web frames have been calculated for nine possible arrangements with the same strength as measured by the design criteria.

From analysis of the results, it is concluded that there is a minimum number of longitudinals necessary to give the minimum structural weight. This number provides the arrangement which results in the maximum spacing of longitudinals at which the minimum required section modulus is obtained. Beyond this, any increase in the number of longitudinals serves to increase the complexity (hence cost)

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of structure at no decrease in weight.

The variation in web spacing produces very little change in weight. There is a small advantage in decreasing the spacing in the ends of the midships three fifths length to provide a gradual transition to end framing conditions. There is a slight penalty, introduced in the total structural weight, when excessive web spacing is used amidships. As a practical matter, web frame spacing appears to be best governed by arrangement advantages and not weight considerations.

The critical factor in determining least weight of structure seems to be the design criteria. Small changes in the required section modulus, l/r of deck longitudinals, and degree of fixity assumed in calculating buckling strength, could lead to far greater changes in the weight of structure than variations in stiffener spacing. Further research into the reduction of ship structural weight might better be applied to evaluating design criteria rather than evaluating framing systems.

Thesis Supervisor: Amelio Milo D'Arcangelo
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May 20, 1957

Professor Leicester F. Hamilton
Secretary of the Faculty
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Cambridge, Massachusetts

Dear Professor Hamilton:

In accordance with the requirements for the Degrees of Naval Engineer and Master of Science in Naval Architecture and Marine Engineering, we submit herewith a thesis entitled: "Weight-Strength Analysis of a Modern Destroyer with Varying Frame Spacings."

Respectfully yours,

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NOTATION

A	Cross-sectional area
a	Length of plating (in the longitudinal direction)
B	Plating Width Factor = $b/t \sqrt{\sigma y/E}$
	Ratio of bending to shear stress in Bleich and Ramsey buckling formula
b	width of plating (in the transverse direction)
a/b	aspect ratio of plating panel (in considering shear stress a/b is the long dimension over the short dimension.)
C	Any coefficient
D	Flexural rigidity of a plate = $Et^3/12(1-u^2)$
E	Modulus of elasticity
H	Hydrostatic head
I	Moment of Inertia of ship or longitudinal
K	Coefficient of buckling in Bryan formula or coefficient of hydrostatic stress in normal loading
L	Length of vessel
l	Length of beam
l/r	Slenderness ratio of longitudinals
M	Bending moment
Q	First moment of area about the neutral axis
r	Radius of gyration of a longitudinal
SF	Safety factor
s	Spacing of longitudinals
t	Thickness of plate
UCS	Ultimate compressive stress
u	Poisson's ratio
V	Vertical shearing force

w pounds per foot of water pressure

x A function of aspect ratio in the Bleich and Ramsey buckling formula

y Distance from neutral axis to extreme fiber

$Z = I/y$ - Section modulus of ship or longitudinal

$\triangle$ Displacement of the ship

ρ Density of water

η Ratio of Young's modulus to tangent modulus in Bleich and Ramsey buckling formula.

σ_1 Primary bending stress = $(M/Z)_{ship}$

σ_2 Secondary or line stress = $(M/Z)_{\substack{longitudinal-plate \\ combination}}$

σ_3 Tiertiary or point stress = $(M/Z)_{plate\ under\ normal\ load}$

σ_i Indicated stress in Bleich and Ramsey buckling formula

σ_{cr} Critical buckling stress in compression

τ Shear stress

τ_{cr} Critical buckling stress in shear

Subscripts

act Actual

all Allowable

cr Critical

h Hogging

hyd Hydrostatic

inst Instability

max Maximum

min Minimum

r Reduced

rqd Required

s Sagging

y Yield point

I. INTRODUCTION

To most naval architects it has become increasingly apparent that the science of ship structural design and analysis has lagged behind that of hydrodynamics, propulsion, and newer fields. Advances in ship structure have been made through improvements in building techniques and materials, but we have not advanced correspondingly in our ability to analyze the relative adequacy of ship structures. Midship Section Design has remained largely a matter of designing an adequate structure from strength considerations, which is, at once, comparatively light in weight, compatable with the desired arrangements, and relatively cheap to construct.

The heart of the design problem lies in the evaluation of the term "adequate strength" in relation to the other factors. To say that a ship which does not exhibit structural weakness is adequate, does not evaluate how over-adequate she may be at a cost to the other factors, particularly weight. There has been an understandable reluctance on the part of structural designers to arrive at a minimum design criteria by trial and error, for error in ship structures is not usually correctable in the trial ship. Only after conclusive experience or in the face of necessity have bold departures been made from past practice.

In no single type of ship has more structural experience been gained, more valuable experimentation been carried out, or has necessity pushed harder than in the destroyer type. Since their inception in the late

nineteenth century, destroyers have been critical in most every design sense, much moreso than other types. The measure of success in destroyer design has been the degree to which the desired military characteristics have been obtained in relation to the overall size of the ship. Thus every design characteristic must, in the destroyer type, be evaluated more in terms of weight and space than in other types. With smaller safety factors, closer tolerances, and lighter scantlings, they represent the maximum yet achieved in the reduction of weight in ship structural design.

It was with these factors in mind that we decided to use a modern destroyer as our guinea pig in the analysis of the relation between the weight, strength, and, to a lesser degree, the arrangements, in a longitudinally framed ship. It was our feeling that perhaps if there were some knowledge of the relative effect upon weight in using a given arrangement of structural members, the arrangements might, at an early stage of the design, be compromised to the least weight structure. We at least hoped to determine what relative magnitude of weight saving is possible purely through the variation in the spacing of the stiffening members. At the same time of course, we are determining what penalty is paid in departing in any direction from the least weight solution.

II. PROCEDURE

2.1 Layout

Having decided to base the calculations on a destroyer type, some typical dimensions were picked and the necessary shell expansion and the shell cross-sections were drawn. It was decided that in order to eliminate the effect of bow and stern framing (not related to the problem of ship girder stresses with which this work is concerned) only the midship three-fifths length of this hypothetical destroyer would be considered. The ends of this section are very close to the points where close-spaced transverse frames are introduced at either end in most destroyers.

In drawing the sections, some typical bulkhead locations and platform deck arrangements were picked and the required main deck openings which would normally be present in a destroyer deck were laid out. This provided the minimum number of invariable factors which it was felt would normally confront the structural designer. The only variation which was later allowed was a two foot movement of transverse bulkheads in the longitudinal direction, to fit the various standard web frame spacings which were later introduced.

Thus, a series of large panels of shell, which were to be stiffened against the loads which were imposed by design criteria, were established. It was determined that in the deck it was impractical to vary the spacing of longitudinals, as the large number of openings made any systematic variation incompatable with arrangement problems. One average

arrangement of longitudinals for the deck, to be used in all studies, was therefore selected. On the sides and bottom, however, a series of grids, longitudinal and transverse, which could be superimposed, one on the other, was established. Thus, the effect of (a) variation of longitudinal spacing on a given web spacing and (b) variation of web spacing on a given longitudinal spacing, could be measured.

For the web systems, a variation from the spacing amidships to a smaller spacing at the ends was established, in order to effect a more gradual transition from midship section scantlings to bow and stern framing scantlings. For consistency a ratio of two to three between the end and midship spacing of web frames was chosen. It was decided that an eight foot spacing amidships, in conjunction with the reduced spacing in the ends, was as close as web frames could be placed without encountering unrealistic arrangement problems in the ends. The spacing amidships was increased by first a small amount (one foot) and than a large amount (four feet) to measure the effect of small and large changes in the longitudinal spacing of webs. Thus, three grid systems of 12'/8', 9'/6', and 8'/5.34' web spacings were established, each of which were plotted on the shell expansion and adjusted for compatibility with the established bulkhead locations.

For longitudinal systems, the spacing was varied from a specified amount at the neutral axis to a closer spacing at the bottom and at the sheer strake. Rather than decide on spacings, the number of longitudinals to be spaced around

the girth and the ratio between the spacing at the neutral axis and the spacing at the bottom and sheer strake plating was selected. A constant value of 1.17 was used for this ratio. Judging from existing designs, twelve longitudinals seemed to be the most likely number for the girth which had been chosen. Accordingly, 15, 12, and 9 longitudinals were chosen to give a variation of 33% more or less than the normal.

The decision to space the longitudinals closer at the bottom and at the sheer strake was based on a suspicion that they would contribute more to the moment of inertia at these locations than at the neutral axis. On the other hand, it was realized that they reduce the required scantlings of the bottom and sheer strake plating, while increasing the minimum thickness of plating at the neutral axis. The relative merits of varying the longitudinals in this manner, against reversing the procedure, are discussed in the appendix.

In a similar manner to that used in adjusting web frames for compatibility with the shell expansion, each longitudinal system was adjusted to the ship. First, the longitudinals were spaced around the girth of the ship. An effort was made to keep the total girth of wide spaced longitudinals at the neutral axis constant in all three longitudinal schemes. Next the strakes were laid out in such a manner that seams were placed within six inches of the transition from narrow to wide spacing. This work was done on a cross-section of the midship section. The girth

readings were then transferred to a shell expansion and the seams and longitudinals were marked off. The longitudinals and strakes could then be run from end to end utilizing platform decks and longitudinal bulkheads as points of longitudinal support, thus eliminating some longitudinals in the ends.

In numbering and tabulating the nine separate schemes, the following nomenclature was chosen:

a) Web Frame Grids

i. 8' spacing amidships, 5.34' spacing at ends----A

ii. 9' " " 6' " " " ----B

iii. 12' " " 8' " " " ----C

b) Longitudinal Frame Grids

i. 9 longitudinals ---------1

ii. 12 " ---------2

iii. 15 " ---------3

Thus, nine separate schemes (1A, 2A, 3A, 1B, 2B, etc.) were calculated, each representing a possible framing system. For each of the nine schemes, there were three calculations of scantlings and weight per foot (one amidships, one forward and one aft) and a web frame weight for each web frame in each scheme.

2.2 Design Criteria

Though it was recognized that many of the design criteria in use in structural design are of questionable merit, it was felt that any great departures from the accepted criteria would tend to detract from the primary purpose of our work, i.e. to determine the relative weight saving which can be obtained solely from variation of stiffener spacings. Therefore, a set of design criteria was established which represented reasonable values of the parameters normally established in destroyer design. In some cases, particularly in designing the end sections, a lack of existing design criteria upon which to base a decision as to what was structurally adequate was found. In these cases, criteria which gave satisfactory results when applied to known successful ships were established.

The important dimensions and design criteria are briefly as follows:

1. Dimensions Assumed: LPB = 410'
   $\triangle$ = 3200 tons
2. Mh (midships) = $\frac{\triangle x L}{C}$ (C = 18) Mh (midships)=73,500 tons-ft.
3. M s(midships) = .75 $\frac{Mh}{Mh}$ = 55,100 tons-ft.
4. σ_1 hog = 19,500 psi
5. σ_1 sag = 14,650 psi
6. required I/y to bottom = $Mh/\sigma_1 h$ = 8,440 $in^2 ft.$
7. required I/y to deck = $Ms/\sigma_1 s$ = 6,340 $in^2 ft.$ (in compression)
8. Material: HTS throughout. Yield strength = 45,000 psi.
9. Mh at after 3L/5 point = .30 Mh amidships = 22,100 tons-ft.

10. Mh at forward 3L/5 point = .15 Mh amidships = 11,050 tons-ft.

11. Shear Force forward, $V = \triangle/C$ $(C = 8) = 400$ tons.

12. Shear Force aft, $V = \triangle/C$ $(C = 6\frac{1}{4}) = 520$ tons.

13. (L/r) max of bottom longitudinals = 30.

14. (L/r) max of deck longitudinals and side longitudinals down to the neutral axis = 55. (See Fig. I)

15. (L/r) max of side longitudinals from neutral axis to bottom-straight line variation with depth from 30 on the bottom to 55 at the neutral axis. (See Fig. I).

16. Hydrostatic Head - a head of water of 4' above the main deck is assumed on all plating amidships and aft, and a variation to 8 feet at the forward end is assumed.

17. All structural members, normally determined by local considerations, are kept constant throughout the design. These include the intercostal docking longitudinal, the center vertical keel, and the side longitudinal normally reserved for spur shores.

18. $\frac{\sigma}{\sigma_{cr}} + (\frac{\tau}{\tau_{cr}})^{1.5} \leq 1$ for all plating subjected to combined shear and direct compression. (See Fig. II)

19. The ultimate compression strength of each panel must be greater than $1\frac{1}{4}$ times σ_1.

20. All plating is considered fully effective in compression except that in the deck only 60 thicknesses of plating associated with each stiffener are considered as effective.

21. All plating under a head of water greater than 15' is assumed to have fully clamped edges. All plating under 6' of water or less is assumed to have simply supported edges.

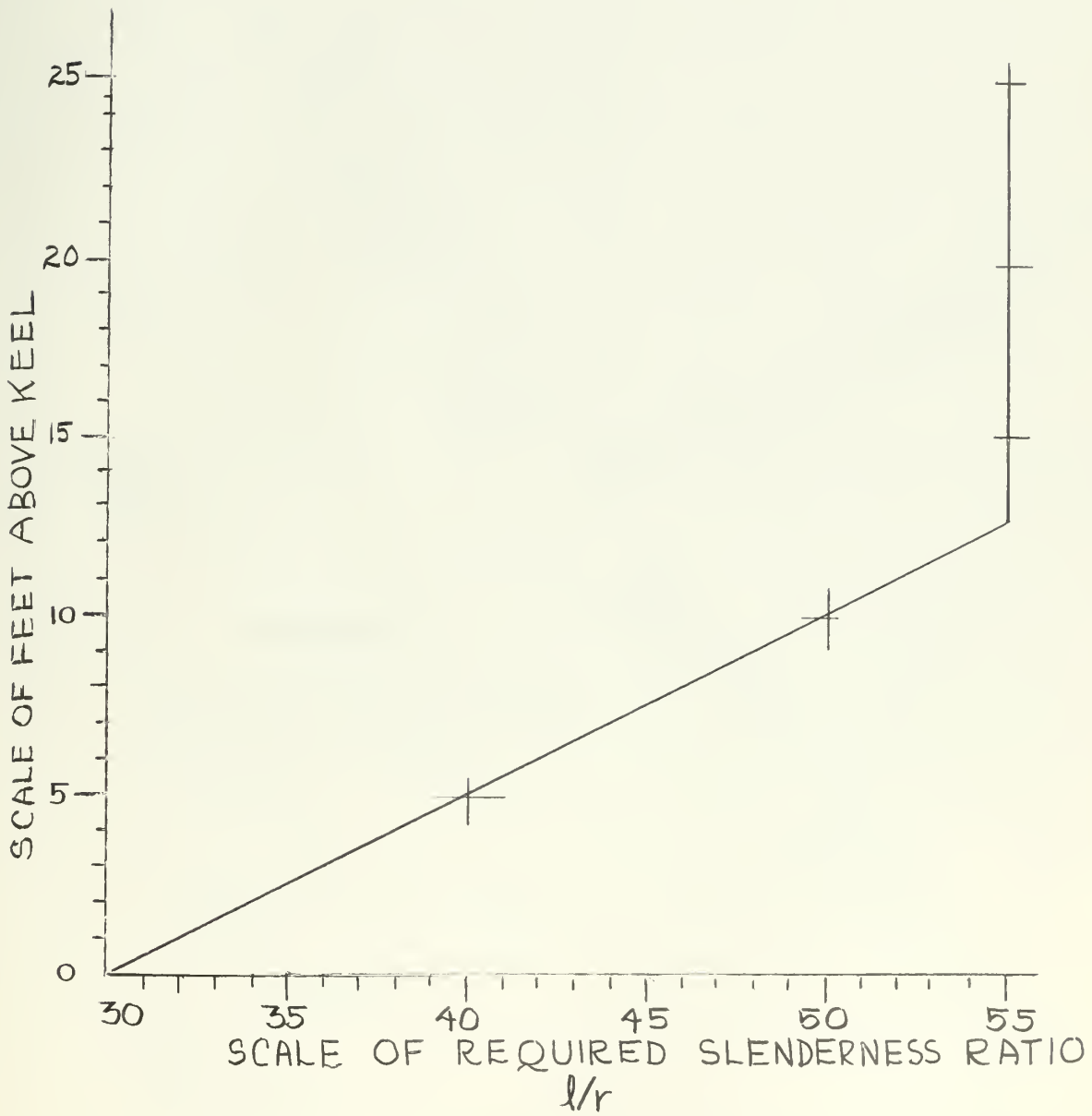
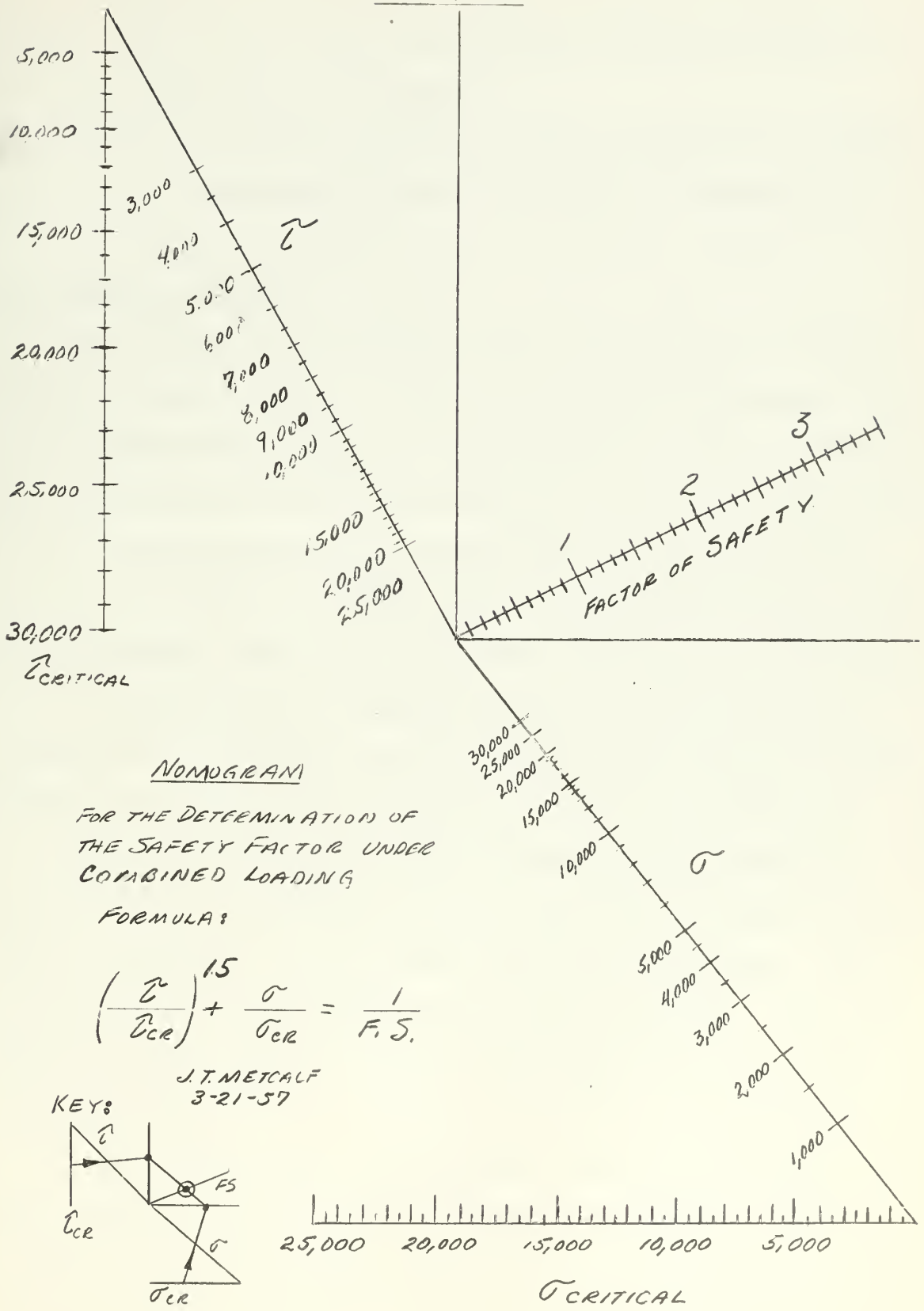


FIGURE I

DESIGN CRITERIA FOR

MINIMUM l/r OF LONGITUDINALS

FIGURE II



NOMOGRAM

FOR THE DETERMINATION OF THE SAFETY FACTOR UNDER COMBINED LOADING

FORMULA:

$$\left(\frac{\tau}{\tau_{CR}}\right)^{1.5} + \frac{\sigma}{\sigma_{CR}} = \frac{1}{F.S.}$$

J. T. METCALF
3-21-57

KEY:

22. No corrosion allowance will be added as such. The uncertainty in choosing the corrosion allowance will serve only to distort the relative effect of variations of parameters.

23. Special design criteria used in end sections appear in Procedure Section under subtitle End Sections, (Section 2.4).

2.3 Midship Section

The midship section design was carried out in a manner similar to that outlined by M. St. Denis in DTMB Report C-555 (On the Structural Design of the Midship Section). Realizing that this method is not necessarily followed in its pure form in most design agencies, we were satisfied that it gives results consistent with those obtained by other methods under similar design criteria. It has the advantage of flexibility for its application to varying sections, such as we have considered. It further lends itself to simplification when dealing with many schemes having similar characteristics.

Starting at the bottom and working up in a girthwise direction, each strake was sized on the basis of hydrostatic load, instability, and ultimate compressive strength, considering both longitudinal and girthwise stresses. The deck plating was also sized for the fixed longitudinal spacing in this manner.

Longitudinals were sized on the basis of limiting ℓ/r and required section modulus of each longitudinal. The docking longitudinal (near the turn of the bilge) was considered invariant and one longitudinal above the neutral

axis was made oversized for spur shore support. In all cases, the lightest standard structural shape of reasonable dimensions was used. No depths greater than 14" were considered.

Section modulus was checked to verify that the assumed value of σ_1 was actually not exceeded. Where section modulus resulted in a value higher than the minimum required, plates which had been slightly over a certain standard plate size were reduced to this plate size (since it was apparent that σ_1 would not be as high as allowed, hence allowed σ_3 would be greater in the refined stress schedule). Where the section modulus resulted in a value lower than the required minimum, the plates in the bottom and/or the sheer strakes were increased in conjunction with the longitudinals which stiffened them. The purpose here, of course, was to add weight where it would do the most good in increasing the section modulus and where the plate was most highly stressed.

2.4 End Sections

On the forward and after ends of the vessel, the scantlings were sized by actual computation. A gradual decrease in the midship scantlings was not used. The design method used at this station was the same basic method as that used amidships. However, some very important variations were necessary. The most important variation made in the design approach was necessary in order to consider the effect of the high shear force in these sections.

In establishing stress schedules for these sections, some means of arriving at a reduced value of σ_1 was

necessary. During the design process this value was selected as:

$$\sigma_{1R} = \sigma_{1\ all} \left(\frac{M_1}{M_2}\right) \left(\frac{Z_2}{Z_1}\right) \qquad (1)$$

where σ_{1R} = Reduced value of σ_1 or the allowable σ_1 value to be designed for.

M_1 = Bending moment at the station.

M_2 = Bending moment at midship station.

σ_{1all} = 8.7 tons per sq. in.

$\frac{Z_2}{Z_1}$ was assumed to equal unity.

Using this value of σ_1, the stress schedules were drawn up in the usual manner, and the shell plating was sized for two different cases. First, the thickness required for ultimate strength under hydrostatic load was computed from

$$t_{hyd} = 0.473b\sqrt{\frac{KH}{\sigma_3}} \qquad (2)$$

This calculation was made for all strakes of shell and deck plating. The second calculation made from the stress schedule was to size the plate for instability, assuming that the plate panels were acted upon only by an edge compressive loading.

$$t_{inst} = 1.92 \times 10^{-4}\ b\ \sqrt{\frac{\sigma_1}{K}} \qquad (3)$$

In order to give due consideration to the effect of the shearing force, the shell plating was sized a third time using the following criteria:

Simply for the purpose of sizing the shell, it was assumed that shear is the only force system acting on the shell. A value of τ_{cr} was then assumed.

In making this assumption, the critical value was related to the yield value in shear, which was a known quantity, by the relationship.

$$\tau_{cr} = \tau_y \frac{1}{S.F.} \qquad (4)$$

where τ_y = 22,800 psi

S.F.= safety factor

When making this assumption, it was recognized that this value of τ_{cr} does not, in fact, represent the actual critical value. Other parameters, notably the panel aspect ratio, and the value of $\frac{b}{t}$ will effect the critical. However, in this stage of the design, it was found that the above approximation produced fairly reliable values of the critical stress, compared to those which were later calculated.

In further refinements of the design process, a closer estimate of the critical value of shear can be obtained by using a method of successive approximations. Once the scantlings have all been sized, it is possible to calculate the value of the critical and this value can be used for the second cycle of calculations. At the forward section the actual values of the critical shear stress intensity at the stringer strake for schemes A, B and C are as follows:

τ_{cr} assumed = 15,300 psi

Scheme A, τ_{act} = 18,250 psi

Scheme B, τ_{act} = 17,650 psi

Scheme C, τ_{act} = 16,750 psi

In arriving at the original assumption of τ_{cr} an arbitrary value of 1.5 was assigned as a safety factor. The safety factors implied by the actual values of τ_{cr} can be found from

$$\text{Factor of Safety} = \frac{22{,}800}{\tau_{cr}} \tag{5}$$

Which gives for

	S.F.
Scheme A	1.25
Scheme B	1.29
Scheme C	1.36

By using the assumed value of τ_{cr} the thickness of plating required to satisfy the shear force, acting by itself, can be found from

$$\tau_{cr} = K_s \frac{\pi^2 D}{t_s b^2} \tag{6}$$

$$t = b \sqrt{\frac{\tau_{crit}}{(26.75 \times 10^6)\ K_s}}$$

let $\tau_{cr} = 15{,}300$

$$t = 2.38 \times 10^{-2} b \sqrt{\frac{1}{K_s}}$$

Having obtained the plate thickness required by each of three separate and independent criteria, the shell plate size was selected as the smallest standard plate which was necessary to satisfy all three cases. It was possible to size longitudinals in accordance with standard methods, in the same manner as at the midship section. Inertia calculations were carried out after all scantlings had been sized. In making the inertia calculations for all of the schemes, the values of area, moment, and lever arm for the

platforms were considered as constants and entered as such.

Once the inertia calculations were completed, it was possible to check the entire section by established design criteria. At this point, however, new design criteria were necessary, in order to give due regard to the interaction of shear and edge compression on the panels. Two separate criteria were used for this analysis. The first was based upon an interaction formula given by St. Denis [10], and the second was based upon the work of Bleich and Ramsey.[3]

First Method.

The interaction formula given by St. Denis considers the case of plate panels under combined shear and edge compression, stressed in compression across the short sides. This formulation is stated as follows:

$$R_s^{1.5} + R_c = \frac{1}{f} \qquad (7)$$

where

$$R_s = \frac{\text{Intensity of applied shear stress}}{\text{Critical shear for simple loading}}$$

$$R_c = \frac{\text{Intensity of applied edge compression}}{\text{Critical stress for simple loading}}$$

f = Factor of safety.

By applying this criterion to similar existing vessels, the value of f was found to vary between 1.25 and 2.0. Accordingly, in the designs of the various schemes, the safety factor was maintained within these limits.

Second Method

This criterion was based upon "A Design Manual or the Buckling Strength of Metal Structure" by Bleich and Ramsey, pg. 41. By using this method the values of σ_{cr} and τ_{cr} can

be determined. These values represent the criticals under the combined effects of both edge compression and shear, and differ from the values of the criticals in the first method in this respect. Consequently, by using the second method an instability failure will occur when either $\sigma_1 = \sigma_{crit}$ or $\tau = \tau_{crit}$. Thus the second method can be expressed as

$$\frac{\sigma_1}{\sigma_{cr}} = \frac{\tau}{\tau_{cr}} = \frac{1}{S.F.}$$

Previous designs indicated that by using this method, the safety factors are slightly higher than the first method and range between 1.4 and 2.4.

The description of the design procedure for the quarter point stations given above and the use of the design criteria specified was the basis for all of the calculations on the end stations. This procedure is one of successive approximations and it may be necessary to carry out a second or even third cycle of calculations. However, the method converges rapidly.

2.5 Web Frame Calculations

Due to the limited time available for this particular phase of the study, it was impractical to attempt nine separate ring frame calculations to determine web frame size. Since one web frame from a ring frame calculation was available for an eight foot spacing on a similar existing ship, it was felt that this could be used as a base, with a suitable percentage variation in weight, as spacing departed from eight feet. This approach, though not exact, was considered to yield results which would not vary appreciably from those derived from nine ring frame

calculations.

The method used to obtain the percentage variation in weight was based on the procedure outlined in Section 28 of the 1954 edition of American Bureau of Shipping Rules. Where departure was made from the rules in regard to depth of web to length ratio, appropriate modification was made to the formulation for the Frame Numeral. The depth of web was chosen to be compatible with the transverse section concerned and such that the Frame Numeral would lie in or near the tabulated range. The web thicknesses were chosen in conformance with Section 28, American Bureau of Shipping Rules, but the hydrostatic head used was that shown in the original design criteria. This departure from Rule procedure was necessary for consistency in design criteria.

Using American Bureau of Shipping Rules, as modified above, the web frame scantlings at a particular transverse section were determined for web spacings from 5.34 feet through 12 feet. Web frame volumes, which correspond to web frame weight, were calculated and this information was placed on a percentage basis with the eight foot web spacing being the base of 100%. Thus, a curve of percentage of 8 foot web frame weight vs. web frame spacing was obtained. This information, in conjunction with a designed web frame, was used to determine total web frame weight. This procedure is detailed in section 2.7 and sample calculations appear in the appendix.

2.6 Determination of Hull Steel Weight between the Forward and After Sections

The only weights included in this analysis were those

which were dependent on design calculations made in this thesis. These were:

1. Main deck plating
2. Main deck longitudinals
3. Shell plating
4. Shell longitudinals
5. Web frames

The inclusion of the weights of items which had been previously determined to be invariant would serve to detract from the relative merit of the various spacing schemes which were calculated. Thus, platform decks and longitudinal bulkheads were included for inertia calculations, where effective, but not in weight calculations.

2.7 Method of Summation of Weights

In determining the total weight of the hull steel in the length considered, it was apparent that items one through four in Section 2.6 lent themselves to a calculation of weight per foot of length in the longitudinal direction. Similarly, item five lent itself to a computation on the basis of weight per foot of girth.

2.7.1 Longitudinal Material

From the inertia calculations, it was one additional step to compute, at each of the stations considered, the weight per foot of longitudinal material.

With three values of weight per foot for each scheme, some method of summation was necessary. Since it was impractical, through lack of time, to obtain additional points on the weight per foot curve, it was decided that some form

of approximate integration would be used to obtain the total weight of longitudinal material. Although it was desirable to obtain representative weights, this study is primarily one of comparison, and it was felt that a small inaccuracy in total weight, through approximate integration, would not materially alter the value of the results; provided, of course, that the method was consistent.

In arriving at the shape of the weight per foot curve, the following items were considered; 1) girth, 2) waterline form, and 3) the shape of the bending moment curves between the three points. All of these factors indicated a parabolic shape, and it was decided that no better method of summation could be made than that resulting from the assumption of a second order parabola for the weight curve. Simpson's first rule was therefore used to integrate the longitudinal weight per foot curve between the three calculation points.

2.7.2 Transverse Material

From the web frame calculations, a curve was derived which showed, on a percentage basis, the weights of web frames spaced at other than eight feet. From the shell expansion, a summation of girths was made for each web spacing for each scheme. With the total girth at each spacing and the weight per foot of girth at each spacing, it was possible to calculate the summation of web frame weight for each scheme. Sample calculations are included in the Appendix.

III. RESULTS

The results of the calculations performed on the various schemes are most easily shown and interpreted by plots of the total weight of the structure vs. the number of longitudinals in the shell. Separate plots showing the weight of shell plating, weight of webs, and weight of longitudinals are included to indicate where any weight saving is possible and its magnitude. A plot of total weight, using a constant eight foot web spacing, is included to show the effect of variations in web spacing. These plots embody the general results of all calculations.

TABLE I

Weight Summary

Scheme	Wgt./ft. for-ward	Wgt./ft. mid-ships	Wgt./ft. aft	Total wgt. of long'l material	Web Frame Weight	Total Weight	% of 2A
1A	2174	3390	2316	734,094	52,234	786,328	1.072
1B	2239	3447	2368	748,084	49,176	797,260	1.085
1C	2313	3577	2423	774,576	38,438	813,014	1.109
2A	1811	3231	2036	682,077	52,234	734,311	1.000
2B	1867	3247	2039	687,172	49,176	738,348	1.005
2C	1943	3327	2090	705,055	38.438	743,492	1.012
3A	1825	3265	1884	681,995	52,234	734,229	1.000
3B	1876	3280	1892	688,462	49,176	737,638	1.006
3C	1949	3342	1941	701,883	38,438	740,320	1.009

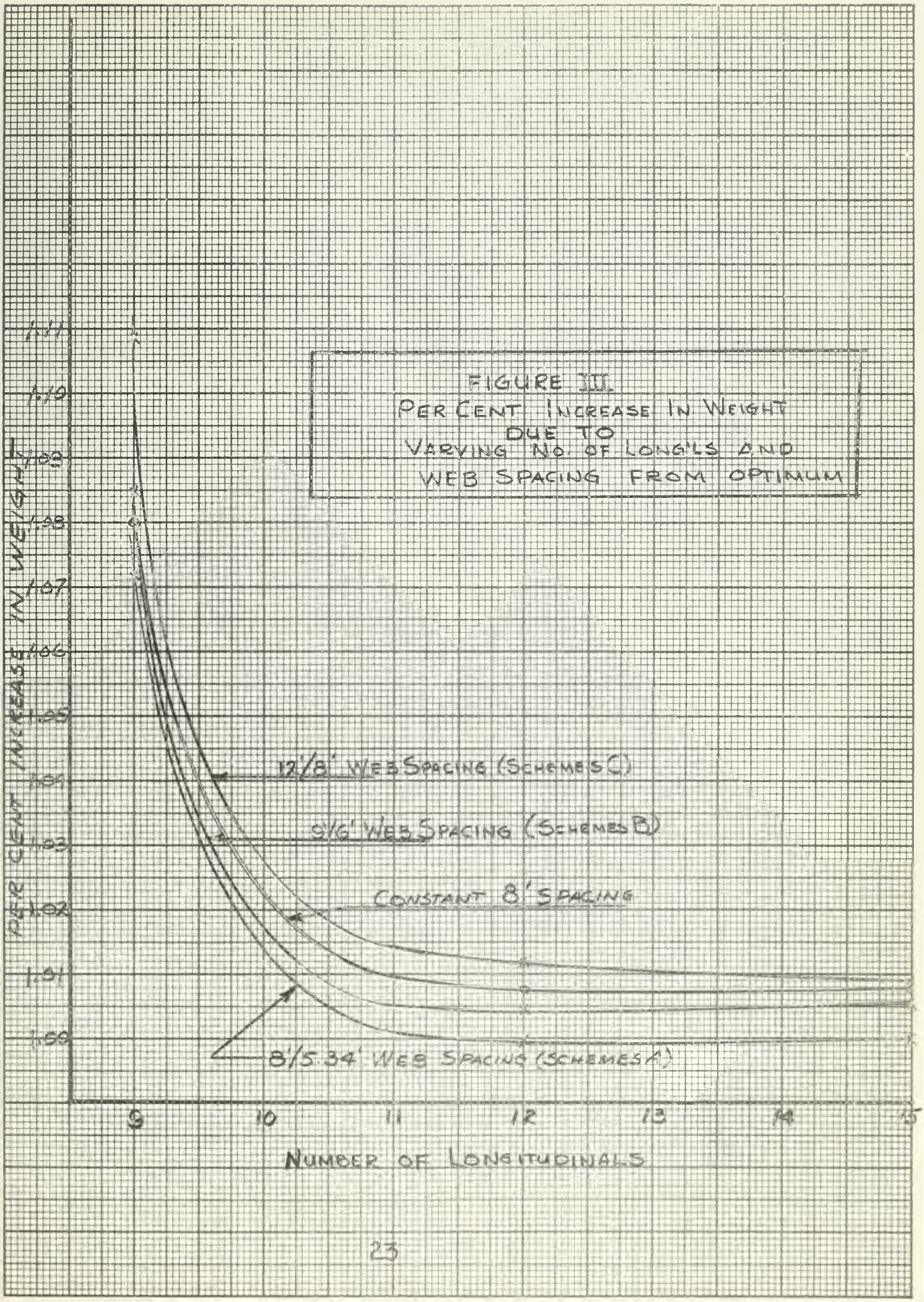


FIGURE III.
PER CENT INCREASE IN WEIGHT
DUE TO
VARYING No. OF LONG'LS AND
WEB SPACING FROM OPTIMUM
PER CENT INCREASE IN WEIGHT
1.11
1.10
1.09
1.08
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1.00
12'/8' WEB SPACING (SCHEMES C)
9'/6' WEB SPACING (SCHEMES B)
CONSTANT 8' SPACING
8'/5.34' WEB SPACING (SCHEMES A)
9
10
11
12
13
14
15
NUMBER OF LONGITUDINALS

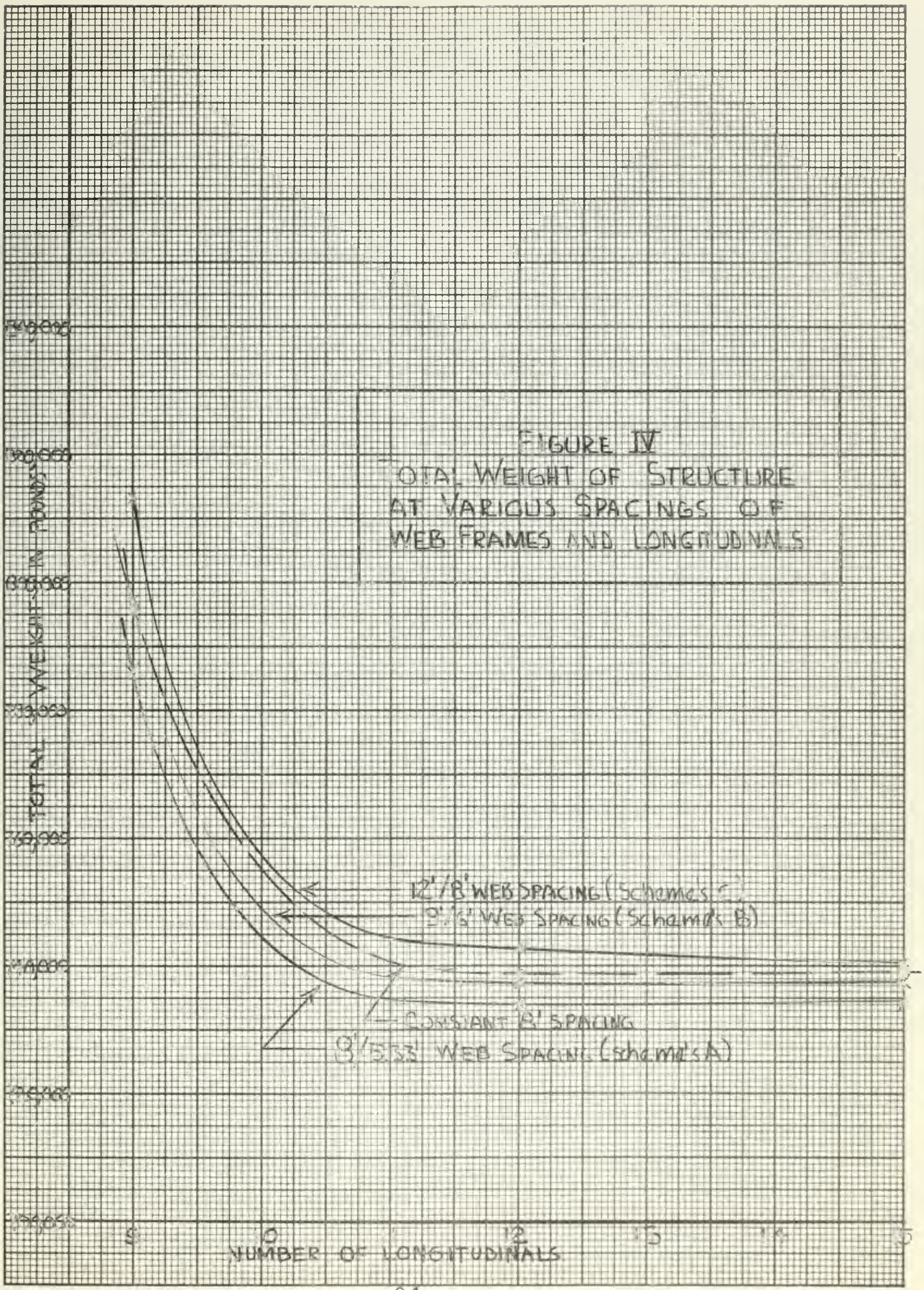


FIGURE IV
TOTAL WEIGHT OF STRUCTURE AT VARIOUS SPACINGS OF WEB FRAMES AND LONGITUDINALS

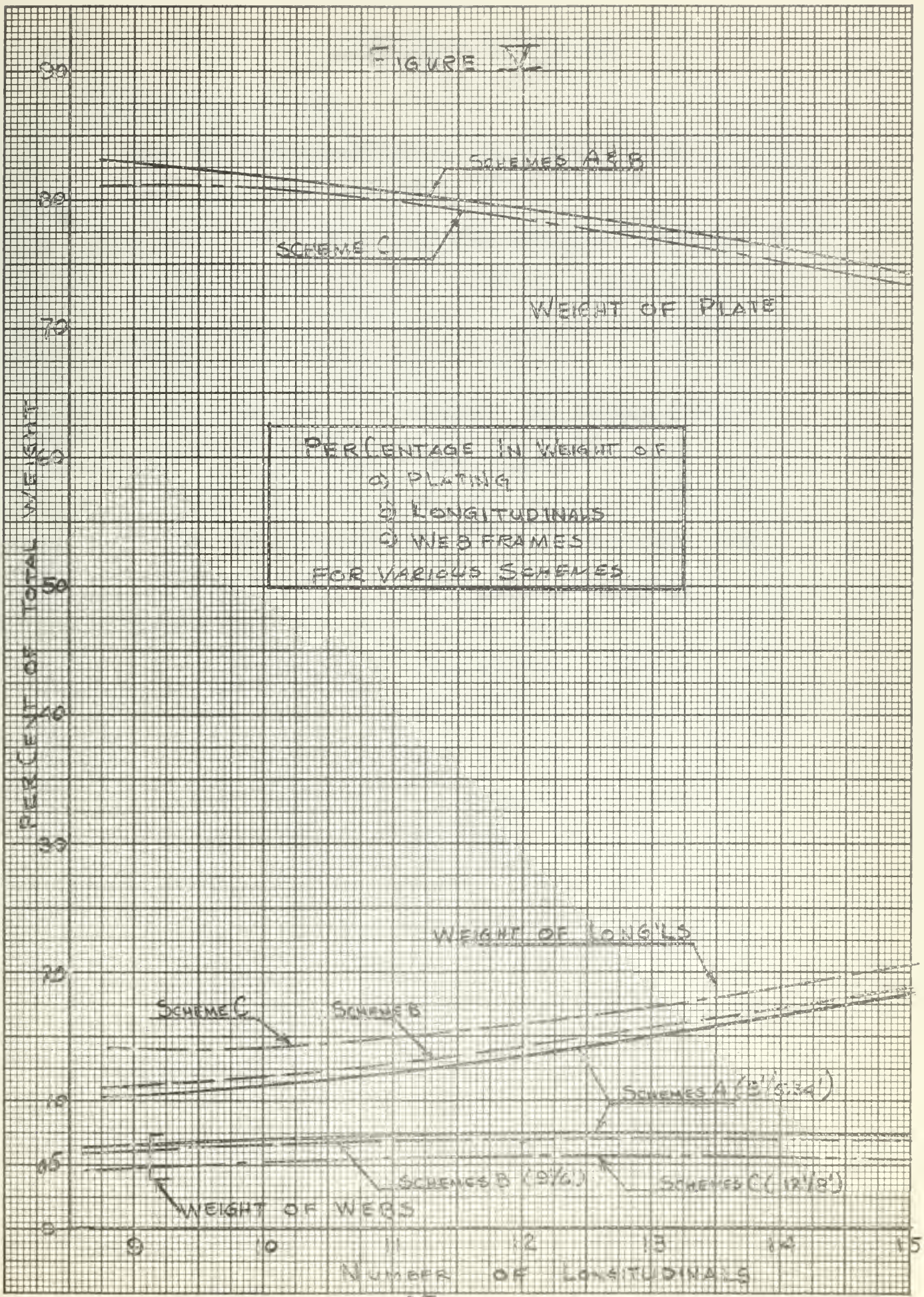


FIGURE V
SCHEMES A & B
SCHEME C
WEIGHT OF PLATE
PERCENTAGE IN WEIGHT OF
a) PLATING
b) LONGITUDINALS
c) WEB FRAMES
FOR VARIOUS SCHEMES
PERCENT OF TOTAL WEIGHT
90
80
70
60
50
40
30
20
10
05
0
WEIGHT OF LONG'LS
SCHEME C
SCHEME B
SCHEMES A (8'/5.34')
SCHEMES B (9'/6')
SCHEMES C (12'/8')
WEIGHT OF WEBS
9
10
11
12
13
14
15
NUMBER OF LONGITUDINALS

IV. DISCUSSION OF RESULTS

4.1 Evaluation of work

From the plots included in the results there are three main facts which are evident.

a) From the plot of per cent increase in weight (Fig. III), the most immediate conclusion to be drawn is that only one per cent of total structural weight can be saved by departing from the use of a standard and constant eight foot web spacing. This small saving was achieved by reducing the web frame spacing in the end sections from 8 feet to 5.34 feet and using a total of twelve shell longitudinals.

b) The plot showing the total weight of structure vs. the number of longitudinals indicates that for all schemes there exists a minimum number of longitudinals which will yield a minimum structural weight. Increasing this number of longitudinals has negligible effect upon the total structural weight. The web spacing has some effect upon this minimum number of longitudinals, although this effect is slight. For our hypothetical ship and our design criteria this number appears to be 10 or 11.

c) The indication of all plots is that by decreasing the web spacing toward the ends some weight saving, for a given number of longitudinals, is possible.

4.2 Significance of Results

The significance of the results stated above can be analysed from the point of view of their overall effect on the design approach which is to be used by the structural designer and the effect this approach will have on the final design.

Item (a) in the evaluation indicates that there is nothing sacred about the traditionally constant web spacing. In fact, by using a variable spacing of webs, a structural weight which is smaller than the constant spacing weight is possible. The calculations made, however, indicate that this weight saving is small and the structural designer may not desire to change his spacing merely to gain one per cent in structural weight. Perhaps the most significant point to be borne in mind concerns the spacing of webs from an arrangement point of view. The calculations have shown that it is to the advantage of the designer to have a larger web spacing amidships and narrow this spacing at the ends of the vessel. This type of web space variation can be used advantageously by the arrangement designer. Within the machinery spaces where webs are used to provide proper foundations for machinery, and where large items of equipment are placed between webs, the larger spacing is desirable. However, outside of the machinery spaces there is no need for such a large spacing. In these areas, since no large pieces of equipment must be fitted between webs, it is possible that the web frames can be spaced in accordance with the dictates of the arrangement studies. In doing so,

the problem of arriving at an efficient arrangement will be somewhat simplified and at the same time the structural weight will decrease.

Item (b) in the evaluation indicates that considerable care must be taken in selecting the number of side longitudinals to be used. For example, if only nine longitudinals had been used, a sacrifice in weight of ten per cent would be incurred. By using more than the minimum number of longitudinals, no weight advantage of importance is gained. However, by using more than the minimum amount, construction costs increase due to the additional amount of welding necessary, and the internal arrangements problem is made somewhat more difficult. Accordingly, from a design viewpoint, it is of the utmost importance to use the minimum number of side longitudinals. This number is a function of the girth of the ship amidships, the material and the web spacing amidships. It represents the maximum spacing of longitudinals with which plate scantlings do not become so large that the minimum required section modulus is exceeded. No formulation for arriving at this number was derived as a result of this thesis and it is recommended that additional work be carried out along these lines because of the importance and significance attached to it.

Item (c) indicates that by decreasing the web spacing, weight saving is realized. This fact, however, has little significance because there is a lower limit under which webs should not be spaced, simply from a practical construction or arrangement point of view. The only significance which

can be attached to this is that if a choice is to be made between two web frame spacings, especially in the end sections of the vessel, the smaller spacing should be selected.

V. CONCLUSIONS

a) The designer has considerable latitude in varying the web frame spacing along the length of the ship, without appreciably affecting the total weight of structure. A constant spacing offers no advantage.

b) Some weight saving is accomplished by reducing the web spacing at the ends from that amidships.

c) Arrangement requirements and studies can dictate the web spacing without sacrificing structural weight.

d) All other things being equal, when a decision regarding the selection of one of two web frame spacings is to be made, the smaller spacing should be selected for it will give the least weight.

e) The number of shell longitudinals used is a critical item and its determination should be made with care.

f) In order to arrive at any weight reduction of structural material, a reanalysis of the existing design criteria seems to be the most promising field.

VI. RECOMMENDATIONS

The calculations which were carried out indicate that the designer has a considerable amount of latitude in varying the spacing of stiffeners without appreciably affecting the total weight of structure. In the design approach and procedure used, however, specific design criteria appeared to have a considerable influence on specific areas where weight might have been saved. This, in fact, is the purpose of design criteria. However, since such importance has been attached to their use and the limitations which they force upon the designer, it may well be worth while to reevaluate the validity of some design criteria. Of paramount importance is the choice of the proper wave characteristics to be used in arriving at the bending moments. Actually, there is little certainty in the present methods of defining the wave profile, and the effect upon the weight and structural design is out of proportion to the trust placed in the original assumption.

A second criteria of design which requires investigation, and a field in which over-design may well be eliminated, deals with the end conditions of those plate panels and longitudinals normally sized from instability considerations. The assumption that fully clamped conditions exist in any panel subjected to more than 15 feet of hydrostatic head neglects the many other factors which have perhaps a greater influence on the degree of fixity which exists. Many panels under no hydrostatic head appear to have a greater degree of fixity than others under heavy

water pressure. In panels normally sized on the basis of instability, considerable weight saving seems feasible through an accurate evaluation of end conditions.

Investigation along the same line could be directed toward the design criteria regarding the limiting value of $\frac{l}{r}$ for longitudinals with the goal of either modifying the existing limits or introducing a new approach to the problem. Limiting the $\frac{l}{r}$ of longitudinals at the neutral axis, for example, seems to be an illogical design criteria in an area where compressive stress is of insignificant magnitude.

These three specific design criteria play a large part in limiting the flexibility of the over-all design approach. Any refinements in these criteria should lead to a design of reduced weight.

Since the calculations which were performed pointed out the importance of initially selecting the minimum number of shell longitudinals, it is recommended that further investigation along this line be carried out. A simple formula which could relate the governing parameters in order to give the designer the number of longitudinals to be used during the first stages of design would be extremely helpful and would by-pass the present method of carrying out additional investigations to determine the optimum number. As a starting point in this investigation, some insight into the method of approach may be gained from the work of St. Denis and Timoshenko. St. Denis deals with the case of a flat unstiffened plate and states that the

required number of stiffeners in the direction of compression can be expressed as

$$n > \sqrt{\frac{\sigma_y}{\sigma_{cr}}} \qquad -1$$

An approach of this type may well be modified to include the effects of shape and varying thickness.

VII. APPENDIX

APPENDIX A

SAMPLE CALCULATIONS

Part I Midship Section - Scheme 2C

Assumed neutral axis: 13' above M.B.L.
(Final calculated neutral axis was 12.91')

(1) Stress Schedule - Strake A

Web Spacing (a) = 12'. Longitudinal Spacing (b)= 36'.
a/b = 4. H = 28'

	Inner Plate Surface Hogging	Outer Plate Surface Sagging
σ_1	-19,500 (see design criteria # 4)	+14,500
σ_2	+ 2,000 (to be verified)	+ 2,000
σ_3	-27,500	+28,500
σ_y	-45,000	+45,000

K = .685

$$t = \frac{b}{12}\sqrt{\frac{K\rho H}{2\sigma_3}} = \frac{b}{12}\sqrt{\frac{64}{2}}\sqrt{\frac{KH}{\sigma_3}}$$

$$= .473\, b\sqrt{\frac{KH}{\sigma_3}} = 17.05\sqrt{\frac{19.85}{27,500}} = .463"$$

Instability check: ends are assumed fixed K = 7.4

$$t = \frac{(1-u^2)}{E}\frac{\sigma_{cr}b^2}{\pi^2 K} = \frac{b}{\pi}\sqrt{\frac{(1-u^2)}{E}}\sqrt{\sigma_{cr}/K}$$

$$= 1.92 \times 10^{-4} \times b\sqrt{\frac{19,500}{7.4}} = .355" \quad \text{(OK)}$$

U.C.S. Check:

$$B = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}} = .03878\,\frac{36}{.463} = 2.81 \quad \text{USR} = .620$$

U.C.S. = .620 x 45,000 = 27,900

1.25 x 19,500 = 24,400 - OK

Therefore: t = .463" is the minimum required thickness

(ultimately used .625" Plate for I/y considerations)

(2) Strake B

WS = 12' LS = 36" a/b = 4 H = 2.83 (scaled)

	I. P. S. (Hogging)	O. P. S. (Sagging)
$\sigma_1 = -19{,}500 \times \frac{12.3}{13}$	= -18,500	+13,500
σ_2	= + 2,000	+ 2,000
σ_3	= -28,500	+29,500
σ_y	-45,000	+45,000

$K = .685$

$$t = .473b \sqrt{\frac{KH}{\sigma_3}} = .445"$$

Instability check and U.C.S. check - okay by inspection with strake A.

(Ultimately used .5625" plate for I/y considerations)

(3) Strake C

WS = 12' LS = 42" a/b = 3.43 H = 26.3 (scaled)

	I. P. S. (Hogging)	O. P. S. (Sagging)
$\sigma_1 = 19{,}500 \times \frac{10.3}{13}$	= -15,400	+11,500
σ_2	+ 2,000	+ 2,000
σ_3	-31,600	+31,500
	-45,000	+45,000

$K = .685$

$$t = .473b \sqrt{\frac{KH}{\sigma_3}} = 19.85 \sqrt{\frac{.685 \times 26.3}{31{,}500}} = .474"$$

Instability Check

$$t = 1.92 \times 10^{-4} \times 42 \sqrt{\frac{15{,}400}{7.4}} = .370" \text{ - OK}$$

U.S.C. Check

$$B = .03878 \times \frac{42}{.504} = 3.23 \qquad \text{U.S.R.} = .587$$

U.C.S. = .587 x 45,000 = 26,400

1.25 x 15,400 = 19,250

t = .474" is the minimum required thickness

(Ultimately used .50" plate as indicated by the stress schedule)

(4) Strake D

WS = 12' LS = 42" a/b = 3.43 H = 21.6

	I. P. S. (Hogging)	O.P.S.(Sagging)	Girthwise
$\sigma_1 = 19{,}500 \times \frac{5.6}{13} =$	- 8,400	+ 6,250	0
σ_2	+ 2,000	+ 2,000	+ 3,000
σ_3	-38,600	+36,750	+42,000
	-45,000	+45,000	+45,000

Longitudinal Criteria

$$t = .473 \times 42 \sqrt{\frac{.685 \times 21.6}{36{,}750}} = .394"$$

Girthwise Criteria

$$t = .473 \times 42 \sqrt{\frac{1 \times 21.6}{42{,}000}} = .430" - \text{(controls)}$$

Instability and U.C.S. Check - okay by inspection with strake A.

(Ultimately used .4375" plate as indicated by stress schedule)

(5) Strake E

WS = 12' LS = 42" a/b = 3.43 H = 14.8'

	I.P.S. (Hogging)	O.P.S. (Sagging)	Girthwise
$\sigma_1 = 19{,}500 \times \frac{2}{12} =$	- 3,000	+ 1,800	0
σ_2	+ 2,000	+ 2,000	+ 3,000
σ_3	-44,000	+41,200	+42,000
	-45,000	+45,000	+45,000

Obviously girthwise stress controls

$$t = .473 \times 42 \sqrt{\frac{14.9 \times 1}{42{,}000}} = .370"$$

(Ultimately used .375" plate as indicated by stress schedule)

(6) Strake F

WS = 12' LS = 36" a/b = 4 H = 7

	I.P.S. (Hogging)	O.P.S. (Sagging)
$\sigma_1 = 19{,}500 \times \frac{11}{13}$	+16,500	-12,300
σ_2	+ 2,000	+ 2,000
σ_3	+26,500	-34,700
	+45,000	-45,000

K = .685

$$t = 17.05 \sqrt{\frac{4.1}{26{,}500}} = .218"$$

Instability Check

Since H is 7' maximum, only simply supported edges can be assumed.

$$t = 1.92 \times 10^{-4} \times 36 \sqrt{\frac{13{,}300}{4}} = .398" \text{ (controls)}$$

U.C.S. Check

$$B = .03878 \frac{36}{.398} = 5.18 \qquad USC = .600$$

U.C.S. = .600 x 45,000 = 27,000

1.25 x 12,300 = 15,400 OK

(Ultimately used .50" plate to match stringer plate and for I/y)

(7) Deck Plating - Strake G (Stringer Plate)

In all deck plating σ_1 is assumed as $\sigma_{1(max)}$

As head is small, instability controls.

Criteria: $\sigma_{cr} = \sigma_1 + \sigma_2/2 = -15{,}500$

WS = 12' LS = 37.5" K = 4 (edges simply supported)

$$t = 1.92 \times 10^{-4} \times 37.5 \sqrt{\frac{15{,}500}{4}} = .480"$$

(Ultimately .5625" plate for I/y)

(8) Deck Plating - Strakes H-K

WS = 12' LS = 37" K = 4 a/b = 3.89

Instability controls

$$t = 1.92 \times 10^{-4} \times 37 \times \sqrt{\frac{15,500}{4}} = .472$$

(used .50" plate as indicated by instability requirements)

(9) Longitudinals (1)-(4) in bottom

A. First Design - Based on t = .50" (20.4# Plate)

$$\sigma_1 = -19,500$$

$$\sigma_2 = -16,500$$

$$\sigma_y/1.25 = -36,000$$

$$r_{(min)} = \frac{12' \times 12}{30} = 4.8$$

$$M_{max} = \frac{wl^2}{12} = \rho Hsl^2/12 = 5.33 \times 29 \times 144 = 802,000\# \text{ in.}$$

$$Z_{min} = \frac{M_{max}}{\sigma_{2max}} = \frac{802,000}{16,500} = 48.5$$

try 10 x 8 x 39# I-T (25.7#) [7.56 in^2]

Z = 49 I = 370 A = 15+7.56 = 22.56

$r = \sqrt{370/22.56} = 4.05$ - too low

try 12 x 8 x 40# I-T (26.9#) [7.92 in^2]

Z = 60 I = 540 A = 15+7.92 = 22.92

$r = \sqrt{\frac{540}{22.92}} = 4.86$ - OK

B. Ultimate Design based on t = .625" (28.05# plate)

For 1 & 2, and .5625" plate (22.95# Pl.) for 3 & 4

try 12 x 8 x 45# I-T (30.4#) [8.95 in^2]

Z = 70 I = 690 A = 23.4+8.95 = 32.4

$r = \sqrt{\frac{690}{324}} = 4.59$ - too low

try T-14 x $6\frac{3}{4}$ x 34# (24.43#) [7.19 in^2]

Z = 74 I = 705 A = 23.4 + 7.2 = 30.6

$r = \sqrt{\frac{705}{30.6}} = 4.80$ - good

therefore #1 & #2 longitudinals are T-14 x $6\frac{3}{4}$ x 34#

For 3 & 4 t = .5625" (22.95#)

required $r = \frac{144}{32} = 4.5$

try T-12 x $6\frac{1}{2}$ x 31# (21.51#) 6.32 in^2

Z = 66 I = 500 A = 19 + 6.3 = 25.3

$r = \sqrt{500/25.3} = 4.45$ - OK

(10) Longitudinal No. 6 - (No. 5 is intercostal docking longitudinal)

$\sigma_1 = 19{,}500 \times \frac{8.8}{13} = -13{,}300$ H = 25'

$\sigma_2 = -22{,}700$ t = 20.4# (.50")

$45{,}000/1.25 = -36{,}000$

$M_{max} = 5.33 \times 25 \times 144 = 691{,}000$ in.#

$Z_{min} = \frac{691{,}000}{22{,}700} = 30.4$

try 12 x 4 x 22# I-T (16.9#) [4.98 in^2]

Z = 32.1 I = 336 A = 15 + 5 = 20

$r = \sqrt{I/A} = \sqrt{336/20} = 4.10$

$l/r = 144/4.10 = 35$ - OK

(11) Longitudinals No. 7 & 8

$\sigma_1 = 19{,}500 \times \frac{6.5}{13} = -9{,}750$ H = 22.5

$\sigma_2 = -26{,}250$ t = 17.85# (.4375")

$-36{,}000$

$M_{max} = 5.33 \times 22.5 \times 42 \times 144 = 726{,}000$

$Z_{min} = \frac{726{,}000}{26{,}850} = 27.0$

try 12 x 4 x 19# I-T (14.9#) [4.39 in^2]

$Z = 27.2 \quad I = 153 \quad A = 11.5 + 4.4 = 15.9$

$r = \sqrt{\frac{153}{15.9}} = 3.10 \quad L/r = \frac{144}{3.10} = 46$ - OK

(12) Longitudinal No. 9

$\sigma_1 \approx 0 \quad \sigma_2 = 36,000 \quad H = 17$

$M_{max} = 5.33 \times 17 \times 43.4 \times 144 = 569,000$ in.# $\quad t = 15.30\#$ (.375")

required $Z = \frac{569,000}{36,000} = 15.8$

try 10 x 4 x 15# I-T (11.7#) [3.45 in^2]

$Z = 17.5 \quad I = 144 \quad A = 8.41 + 3.45 = 11.86$

$r = \sqrt{\frac{144}{11.86}} = 3.5 \quad L/r = 41.2$ - OK

(13) Longitudinals No. 11 & 12 (No. 10 is invariable)

$\sigma_1 = -14,500 \times 9/13 = -10,900 \quad H = 10$

$\sigma_2 \quad \underline{-25,100} \quad t = 20.40\#(.50")$

$-36,000$

$M_{max} = 5.33 \times 10 \times 36 \times 144 = 276,000$

$Z_{min} = \frac{276,000}{25,000} = 12.7$

try 8 x 4 x 13# I-T (10.0#) [2.94 in^2]

$Z = 12.9 \quad I = 95 \quad A = 15 + 2.9 = 17.9$

$r = \sqrt{95/17.9} = 2.3 \quad L/r = 63$ - too high

try 10 x 4 x 11.5# I-T (9.1#) [2.67 in^2]

$Z = 13.8 \quad I = 125 \quad A = 15 + 2.67 = 17.7$

$r = \sqrt{125/17.7} = 2.68 \quad L/r = 54$ - OK

(14) Deck Longitudinals

Obviously L/r will control as H is only 4'.

For t = .5625"

try 8 x 4 x 15# I-T (11.3#) $[3.33\ in^2]$

$Z = 15.3 \quad I = 116 \quad A = 18 + 3.3 = 21.3$

$r = \sqrt{116/21.3} = 2.34 \quad L/r = 61$ - too high

try 10 x 4 x 15# I-T (11.7#) $[3.45\ in^2]$

$Z = 18.2 \quad I = 170 \quad A = 18 + 3.5 = 21.5$

$r = \sqrt{170/21.5} = 2.82 \quad L/r = 51$ - OK

For t = .500"

The 10 x 4 x 11.5# I-T will satisfy design criteria but the 10 x 4 x 15# I-T is required for I/y. Therefore all deck longitudinals are the same.

Part II - Forward Section - Scheme 2C

Assumed Neutral Axis: 16' above M.B.L.
(Final calculated neutral axis was 15.77')

(1) Stress Schedule - Strake A

Web Spacing (a) = 8'. Longitudinal Spacing (b) = 37".
$a/b = 2.6 \quad H = 35.9$

Reduced $\sigma_1 = 19{,}500 \left(\frac{M_1}{M_2}\right)\left(\frac{Z_2}{Z_1}\right) = 3{,}050$ psi. (see procedure)

	Inner Plate Surface Hogging	Outer Plate Surface Sagging
σ_1	- 3,050	+ 3,050
σ_2	+ 2,000 (to be verified)	+ 2,000
σ_3	-43,950	+39,950
σ_y	-45,000	+45,000

$K = 0.685$

$$t = \frac{b}{12}\sqrt{\frac{K\rho H}{2\sigma_3}} = 0.473b\sqrt{\frac{KH}{\sigma_3}}$$

$t = 0.434$ in.

Instability check: (ends assumed fixed, K = 7.85)

$$t = 1.92 \times 10^{-4} b\sqrt{\frac{\sigma 1}{K}} = 0.140"$$

Therefore, the thickness calculated checks for instability.

U.C.S. Check

$$B = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}} = 3.84$$

From Chart F = 0.500

U.C.S. = 0.50 (45,000) = 22,500

1.25 x (3,050) = 3,920

Therefore, the minimum required thickness is

t = 0.434 for Strake A.

(Ultimately used 17.85# Plate, .4375 in.)

(2) Strake B.

WS = 8' LS = 36" a/b = 2.6 H = 33'

	I.P.S. (Hogging)	O.P.S. (Sagging)
$\sigma_1 = -3,050\left(\frac{12.5}{16.0}\right) =$	- 2,300	+ 2,300
$\sigma_2 =$	+ 2,000	+ 2,000
$\sigma_3 =$	-44,700	+40,700
σ_y	-45,000	+45,000

K = 0.685

$$t = .473b\sqrt{\frac{KH}{\sigma_3}} = 0.400 \text{ in.}$$

Instability and U.C.S. check by inspection and comparing with Strake A.

(3) Strake C.

b = 36 K = .685 H = 28.40

	I.P.S. (Hogging)	O.P.S. (Sagging)
$\sigma_1 = -3{,}050\left(\frac{7.8}{16.0}\right) =$	- 1,430	+ 1,430
σ_2	+ 2,000	+ 2,000
σ_3	-45,570	+41,570
σ_y	-45,000	+45,000

$$t = .473b\sqrt{\frac{KH}{\sigma_3}} = 0.378$$

(4) Strake D (Neutral Axis)

b = 36" $K_B = .685$ H = 18.65 a/b = 2.6

Girthwise criteria controls plating size.

$$t = \frac{36}{12}\sqrt{\frac{0.5(64)(18.65)}{42{,}000}} = 0.357 \text{ in.}$$

(5) Strake E.

b = 36 H = 16.15 a/b = 2.6

	I.P.S. (Hogging)	O.P.S. (Sagging)
$\sigma_1 = -3{,}050\left(\frac{4.5}{14.6}\right) =$	- 940	+ 940
σ_2	+ 2,000	+ 2,000
σ_3	-46,060	+42,060
σ_y	-45,000	+45,000

$$t = .473(36)\sqrt{\frac{(.685)(16.15)}{42{,}060}} = 0.275 \text{ in.}$$

(6) Strake F (Shear Strake) H = 10.15

	I.P.S. (Hogging)	O.P.S. (Sagging)
$\sigma_1 =$	- 3,050	+ 3,050
σ_2	+ 2,000	+ 2,000
σ_3	-43,950	+39,050
σ_y	-45,000	+45,000

$$t = .473(36)\sqrt{\frac{(.685)(10.15)}{39{,}050}} = .228$$

(7) Main Deck, sized for edge compression alone

Stress Schedule same as Strake F.

$$b = 31" \qquad H = 8'$$

$$t = \underline{0.196 \text{ in.}}$$

(8) After sizing all strakes of plate as above, it was again sized, assuming plate panels were acted upon simply by a shearing force, and the minimum thickness required to resist critical buckling was computed.

$$\tau_{cr} = 15{,}300 \quad \text{(see procedure)}$$

$$\tau_{cr} = 26{,}750{,}000 \left(\frac{t}{b}\right)^2 K_s$$

$$t = 0.0238\, b \sqrt{\frac{1}{K_s}}$$

Summarizing the shear calculations, the following results were obtained:

Strake	a/b	K_s	t
G	3.1	6.2	0.296 in.
H	3.55	5.9	0.264
J	3.2	6.0	0.291
K	3.69	5.9	0.254
F	2.68	6.5	0.336
E	2.74	6.4	0.326

Strake A, B, C, and D were governed by hydrostatic conditions, while all other strakes were governed by the shear condition.

(9) Longitudinals (1)-(4) in bottom.

A. Designed on base of t = 0.4375" (17# plate)

$$\sigma_1 = -3{,}050$$

$$\sigma_2 = \underline{-32{,}950}$$

$$\sigma_y/1.25 = -36{,}000$$

$$r_{min} = \frac{96}{30} = 3.2$$

$$M_{max} = \frac{-wl^2}{12} = \frac{\rho H_s l^2}{12} = 428{,}000 \text{ psi.}$$

$$Z_{min} = \frac{M_{max}}{\sigma_2} = \frac{428{,}000}{32{,}950} = 13.$$

using a 10" x 4" x 11.5" I-T

$Z = 13.65$ $\quad A = 2.67 + 11.48 = 14.15$

$I = 121$

$$r = \sqrt{\frac{121}{14.15}} = 2.92$$

Therefore, a 10" x 4" x 11.5# I-T should be used for longitudinals 1, 2, 3, and 4.

(10) Longitudinal 6 (Note that No. 5 is intercostal)

$M_{max} = 334{,}000$

$Z_{req} = 9.65$

Using an 8 x 4 x 10# I-T

$Z = 9.89$ $\quad A = 2.23 + 8.44 = 10.67$

$I = 72$ $\quad r = \sqrt{\frac{72}{10.67}} = 2.6$

$\frac{l}{r} = 36.8$ which is acceptable.

(11) Longitudinals 8 and 9

$\sigma_1 = 0$ $\quad H = 19$ $\quad t = 15\#$ plate

$\sigma_3 = 36{,}000$ $\quad S = 35$

$M_{max} = 226{,}000$ $\quad Z_{req} = \frac{226{,}000}{36{,}000} = 6.3$

Using a 6" x 4" x 6.2# I-T

$I = 34$ $\quad A = 10.26$

$K = 1.8$ $\quad \frac{l}{r} = 53.5$

(12) Longitudinals 11 and 12.

At these positions the $\frac{l}{r}$ criterion governs

Using a $\frac{1}{2}$ - 12" x 3" x 11,8" Jr Bm. (5.9#)

$I = 32$ $\qquad$ $A = 8.815$

$r = 1.9$ $\qquad$ $\frac{l}{r} = 51$

(13) The same size longitudinal was used throughout the deck.

(14) After sizing all scantlings inertia calculations were made and the stringer plate checked for instability by two methods.

(15) First the shear in the stringer plate was found.

$$\tau = \frac{VQ}{It}$$

$V = 406$ tons (Design Criteria)

$I = 81{,}372$ ft^2in^2 (from Inertia Calculation)

$t = 0.3125$ in. (from Plating Calculations)

$Q = 15.67\ (82.04) = 1{,}289$ $(Q = y \times A)$

Then

$$\tau = 4{,}040 \text{ psi.}$$

From interaction formula (see Procedure).

$$\frac{\sigma_1}{\sigma_{cr}} + \left(\frac{\tau}{\tau_{cr}}\right)^{1.5} = \frac{1}{S.F.}$$

$$\sigma_{cr} = K\frac{\pi^2 D}{tb^2} \qquad \tau_{cr} = K\frac{\pi^2 D}{tb^2}$$

$D = 83{,}840$ $\qquad$ $b = 31$ $\qquad$ $K_s = 6.07$

$t = 0.3125$ $\qquad$ $K_\sigma = 4$

$\sigma_{cr} = 11{,}050$ $\qquad$ $\tau_{cr} = 16{,}750$

$$\frac{\sigma_1}{\sigma_{cr}} + \left(\frac{\tau}{\tau_{cr}}\right)^{1.5} = \frac{1}{S.F.}$$

$$\frac{4,900}{11,050} + \left(\frac{4,040}{16,750}\right)^{1.5} = \frac{1}{S.F.}$$

$$S.F. = 1.45$$

(16) Using the method of Bleich & Ramsey (See Procedure)

$$\frac{a}{b} = 3.1$$

$$B = \frac{\sigma_1}{\tau} = \frac{3,050}{4,040} = 0.75$$

$$X = \frac{4}{3} + \frac{1}{\left(a/b\right)^2} = 1.43$$

$$K = 2x^2 \; B\sqrt{B^2 + 3}\left[-1 + \sqrt{1 + \frac{4}{B^2x^2}}\right]$$

$$K = 6.45$$

$$\frac{\sigma_i}{\eta} = 26,750,000 \left(\frac{t}{b}\right)^2 K$$

$$\frac{\sigma_i}{\eta} = 17,420 \quad (\eta = 1)$$

$$\tau_{cr} = \frac{\sigma_i}{\sqrt{B^2+3}} = 9,240$$

Then

$$\frac{\sigma_1}{\sigma_{cr}} = \frac{\tau}{\tau_{cr}} = \frac{1}{S.F.}$$

$$\frac{4,040}{9,240} = \frac{3,050}{6,920} = \frac{1}{2.28}$$

$$S.F. = 2.28$$

Part III After Section - Scheme 2C

Assumed N.A.: 14.5' above M.B.L.

Final Calculated N.A. was 13.89' above M.B.L.

(1) Strake A (between #1 and #2 longitudinal)

Web Spacing (a) = 8' Long. spacing (b) = 35"

a/b = 2.74 H = 26'

Stress Schedule - Assume 6.5 tons/in^2 in keel (ie. 14,600 psi)

$\sigma_1 = \frac{11.5}{14.5} \times 14{,}600 = +11{,}600$

$\sigma_2 = +2{,}000$

$\sigma_3 = +31{,}400$

$+45{,}000$

Hydrostatic

$$t = .473(b)\sqrt{\frac{KH}{\sigma_3}} = .473(35)\sqrt{\frac{.685(26)}{31{,}400}} =$$

$$16.59(2.38 \times 10^{-2}) = .394"$$

Instability

$$t = 1.92 \times 10^{-4}(b)\sqrt{\frac{\sigma_1}{K}} = 1.92 \times 10^{-4}(35)\sqrt{\frac{11{,}600}{7.75}}$$

$$= 67.2 \times 10^{-4}(38.7) = .26"$$

Girthwise $\sigma_1 + \sigma_2 + \sigma_3 = 0 + 3000 + 42000 = 45{,}000$

$$t = .473(35)\sqrt{\frac{1.0\ (26)}{42{,}000}} = .414"$$

(Used .4375" plate, 17.85#)

Ult. Comp. Strength Check

$$B = .03878\ \frac{b}{t} = .03878\ \frac{35}{.4375} = 3.1 \quad \text{Ratio} = .60$$

U.C.S. = .60 (45,000) = 27,000

$1.25\sigma_1 = 1.25\ (11{,}600) = 14{,}500$ (OK)

(2) Strake B - between #2 and #3 longitudinal

WS = 8' LS = 35" H = 29'-5' = 24'

$\sigma_1 = \frac{9.5}{14.5} \times 14{,}600 = 9{,}600$

$\sigma_2 \qquad 2{,}000$

$\sigma_3 \qquad 33{,}400$

Hydrostatic

$$t = .473(35)\sqrt{\frac{.685(24)}{33{,}400}} = 16.59(2.22 \times 10^{-2}) = .372$$

Girthwise

$$t = 16.59\sqrt{\frac{1.0(24)}{42{,}000}} = .396" \qquad \text{controls}$$

Instability and Ult. Compr. Strength OK by inspection with Strake A. (Used 17.85# plate, .4375")

(3) Strake C

WS = 8' LS = 35" H = 29'-7' = 22'

$\sigma_1 = \frac{7.5}{14.5} \times 14{,}600 = 7{,}600$

$\sigma_2 \qquad 2{,}000 \qquad a/b = 2.74$

$\sigma_3 \qquad 35{,}400 \qquad K_s = 6.20$

$45{,}000$

Hyd:

$$t = 16.59\sqrt{\frac{.685(22)}{35{,}400}} = .342"$$

Girth:

$$t = 16.59\sqrt{\frac{1.0(22)}{42{,}000}} = .380" \qquad \text{controls}$$

Shear Instab:

$$t = 2.38 \times 10^{-2}(35)\ \frac{1}{\sqrt{6.20}} = .334"$$

(Used 15.3#, .375" - This was OK since N.A. was lower than assumed 14.5'.)

(4) Strake D

WS = 8' LS = 35" H = 20.25

Girth:

$$t = .473(35)\sqrt{\frac{1.0(20.25)}{42,000}} = .364"$$ controls

Shear instability same as Strake C.

Instability & Ult. Comp. Str. OK by inspection

(Used 15.3#, .375")

(5) Strake E - between #9 longitudinal and platform.

WS = 8' LS = 35" H = 13.5

Girthwise:

$$t = 16.59\sqrt{\frac{1.0(13.5)}{42,000}} = .298$$

Shear Instability $t = 2.38 \times 10^{-2}(35)\frac{1}{\sqrt{6.20}} = .334"$

controls

(Used 14.02#, .3437")

(6) Strake F - between #12 longitudinal and deck

WS = 8' LS = 31.5" H = 5.75'

$\sigma_1 = \frac{9.25}{14.5} \times 14,600 = 9,200$

$\sigma_2 \qquad 2,000$

$\sigma_3 \qquad \frac{33,800}{45,000}$

Instability

$$t = 1.92(31.5) \times 10^{-4}\sqrt{\frac{9200}{4}} = .290"$$

Shear Instability

$$t = 2.38 \times 10^{-2}(31.5)\frac{1}{\sqrt{6.09}} = .304$$ controls

$K_s = 6.09$

(Ultimately use 15.3# plate, .375" for closer match to deck and for I/y considerations)

(7) Deck Plating

$$\sigma_1 = \frac{10.5}{14.5} \times 14{,}600 = 10{,}600$$

Strake C - largest spacing of longitudinals

WS = 8' LS = 38" a/b = 2.52

Instability

$$t = 1.92 \times 38 \times 10^{-4}\sqrt{\frac{10{,}600}{4}} = .375$$

Shear Instability $K_s = 6.3$

$$t = 2.38 \times 10^{-2}(38)\frac{1}{\sqrt{6.3}} = .36"$$

(Used 15.3#, .375")

Strake D - Stringer plate - On the basis of the above, since b = 35", 15.3# plate would be OK. Later, a check of combined stress and I/y required an increase to 17.85# plate.

Strake B.

Instab: $t = \frac{34.5}{38} \times .375 = .340"$

could use 14.02# on the basis of above, but this strake was increased to 15.3# for I/y.

Strake A

(Used 14.02#)

(9) Longitudinals #1 and #2

(#3 and #4 terminated well forward of this station)

$\sigma_1 = \frac{14.5-2}{14.5} \times 14{,}600 = 12{,}600$ H = 27' l = 8'

σ_2 23,400 s = 35"

36,000

A. #1 long.

$M = 5.33\ Hsl^2 = 5.33(8)^2 Hs = 341\ Hs = 322{,}000$

$Z = \frac{M}{\sigma_2} = 13.78$ $\quad t = .4375\#$ $\quad A_{pl} = 11.48"$

$(l/r)_{rqd} = 34.2$ $\quad r_{rqd} = {}^{96}/_{34.2} = 2.8$

$r^2A \approx 110$

Try 10 x 4 x 11.5# I-T (9.1#)(2.67$^{\square"}$) I = 121 Z=13.7

$r = \sqrt{\frac{121}{14.5}} = 2.93$ $\quad L/r = {}^{96}/_{2.93} = 32.8$ $\quad$ OK

B. #2 same

Note: Bulkhead runs in way of #3 longitudinal
Shafting runs in way of #4 longitudinal

(10) Longitudinals #5 through #7 $\quad t = .375"$ $\quad A_p = 8.44$

$\sigma_1 = \frac{14.5-7}{14.5} \times 14{,}600 = 7{,}600$ $\quad H = 29-7 = 22'$

$\sigma_2 \qquad\qquad 28{,}400$ $\quad s = 35"$

$36{,}000$

$M = 341\ Hs = 262{,}200$ $\quad Z = \frac{262{,}200}{28{,}400} = 9.25$

$L/r_{rqd} = 43.2$ $\quad r_{rqd} = {}^{96}/_{43.2} = 2.22$ $\quad r^2A \approx 54$

Try 8 x 4 x 10# I-T (7.6#)(2.23$^{\square"}$) I = 67 $\quad$ Z = 9.8

r = 2.51 $\quad L/r = 38.2$ $\quad$ OK

(11) Longitudinals #8 and #9

$\sigma_1 = \frac{14.5-11.5}{14.5} \times 14{,}600 = 3{,}100$ $\quad H = 29-13.5 = 15.5'$

$\sigma_2 \qquad\qquad 31{,}900$ $\quad s = 35"$

$36{,}000$ $\quad t = .375"$ $\quad A_p = 8.44$

$M = 341Hs = 185{,}000$ $\quad Z = \frac{185{,}000}{31{,}900} = 5.83$

$l/r_{rqd} = 52$ $\quad r_{rqd} = {}^{96}/_{52} = 1.85$ $\quad r^2A \approx 38$

Try $1/2$ - 12 x 4 x 14# Joist (7.0#)(2.07$^{\square"}$)

$I = 39.7$ $\quad Z = 6.09$ $\quad A_T = 10.51$

$r = 1.945$ $\quad 1/r = 49.4$ $\quad$ OK

#10 longitudinal ties into platform

(12) Longitudinal #11 and #12

$\sigma_1 = \frac{22-14.5}{14.5} \times 14{,}600 = 7{,}600$ $\quad H_m = 9.5'$

$\sigma_2 \qquad\qquad\qquad\qquad 28{,}400$ $\quad t = .375"$ $\quad A_p = 8.44$

$\qquad\qquad\qquad\qquad\qquad\quad 36{,}000$

Use the head for #11 longitudinal and the above stress schedule based on #12 longitudinal.

$M = 341\ Hs = 341(9.5)(31.5) = 102{,}000$

$Z = \frac{102{,}000}{28{,}400} = 3.6 \quad (1/r)_{rqd} = 55 \therefore$

$r_{rqd} = 96/55 = 1.745$

$r^2A \approx 33$ or 34

Try $\frac{1}{2}$ - 12 x 3 x 11.8# Jr.Bm (5.9#)(1.725$^{\square"}$)

$I = 33$ $\quad r = 1.802$ $\quad 1/r = 53$ $\quad$ OK

(13) Deck Longitudinals

$\sigma_1 = \frac{25-14.5}{14.5} \times 14{,}600 = 10{,}600$

$\sigma_2 \qquad\qquad\qquad\qquad 25{,}400$ $\quad H = 4'$

$\qquad\qquad\qquad\qquad\qquad\quad 36{,}000$

For #13 and 14 $\qquad s = 36\frac{1}{2}$

$M = 341\ Hs = 49{,}700 \quad Z = \frac{M}{\sigma_2} = 1.92$

$1/r_{rqd} = 55 \quad \therefore \quad r_{min} = 96/55 = 1.75$

$t = .375"$ $\quad (15.3\#) \qquad\qquad A_p = 8.44$

Try $\frac{1}{2}$ - 12 x 3 x 11.8# Jr.Bm. (5.9#)(1.72"")

$Z = 6.1 \qquad I = 33.5 \qquad A_T = 10.52$

$V = \sqrt{\frac{33.5}{10.52}} = 1.784 \qquad l/r = \frac{96}{1.784} = 53.7^{\#}$ OK

If plate boosted to .4375

$\frac{1}{2}$ - 12 x 3 x 11.8# Jr Bm.

$Z = 6.2 \qquad I = 35.5 \qquad A_{pl} = 11.48$

$r = \sqrt{\frac{35.5}{13.20}} = 1.64 \qquad A_t = 13.20$

Try $\frac{1}{2}$ - 12" x 4" x 14# Joist (7.0#)(2.07""")

$Z = 7.7 \qquad I = 42$

$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{42}{13.55}} = 1.76 \qquad l/r = 54.5$ (OK)

Use $\frac{1}{2}$ - 12" x 4" x 14# Joist for #13 and #14

Use $\frac{1}{2}$ - 12" x 3" x 11.8# Jr.Bm. for #15, 16, 18, 19.

Summary of Inertia Calculations

Scheme 2C

$I = 46{,}991 \text{ in}^2\text{ft}^2$

N.A. above baseline = 13.89'

y deck = 11.11'

Max Stresses Compr. Deck 5.25 tons/in^2

Keel 6.55 "

(14) Stringer Plate Check

First Method:

$$A_{deck} = \begin{cases} 144 \times .375 = 54.0 \\ 76 \times .4375 = 32.2 \end{cases} = 86.2 \text{ in}^2$$

$A_{long} = 15.73 \text{ in}^2 \qquad I = 46{,}911 \text{ in}^2\text{ft}^2$

$Q = 86.2(11.11) + 15.73(10.8) = 957 + 170 = 1127 \text{ in}^2\text{ft.}$

$$\tau = \frac{VQ}{tI} = \frac{520.3(2240)(1127)}{(46991)(.4375)} = 6400 \text{ psi.}$$

$\sigma_1 = 5.25 \times 2240 = 11{,}720$ psi.

$$\sigma_{cr} = 4 \times \frac{\pi^2 \times 230050}{(35)^2 \times .4375} = 16{,}950 \text{ psi.}$$

$$\tau_{cr} = \frac{6.2}{4} \times 16{,}950 = 26{,}300 \text{ psi.}$$

$$\frac{\sigma_1}{\sigma_{cr}} + \left(\frac{\tau}{\tau_{cr}}\right)^{1.5} = \frac{11{,}720}{16{,}950} + \left(\frac{6{,}400}{26{,}300}\right)^{1.5} = .691 + .120 = .811$$

S.F. = 1.23

Second Method: $I = 46{,}911 \text{ in}^2\text{ft}^2$

$V = 520.3$ tons $\qquad t = .4375"$

$Q = 1127 \text{ in}^2\text{ft.} \qquad b = 35"$

$\tau = 6{,}400$ psi.

$\sigma_1 = 11{,}720$

$$B = \frac{\sigma_1}{\tau_{xy}} = \frac{11{,}720}{6{,}400} = 1.835$$

$B^2 = 3.365 \qquad \sqrt{B^2 + 3} = 2.52$

$a/b = 96/35 = 2.74 \qquad X = 4/3 + \frac{1}{(2.74)^2} = 1.46$

$X^2 = 2.135$

$$K = 2X^2 \, B\sqrt{B^2 + 3}\left[-1 + \sqrt{1 + \frac{4}{B^2 X}}\right]$$

$$K = 2(2.135)(1.835)(2.52)\left[-1 + \sqrt{1 + .814}\right]$$

$K = 6.84$

$$\frac{\sigma_i}{\eta} = 26{,}750{,}000 \left(\frac{t}{b}\right)^2 K = 28{,}550 \text{ psi}$$

$\eta = 1$

$$\tau_{cr} = \frac{\sigma_i}{\sqrt{B^2+3}} = \frac{28,550}{2.52} = 11,300$$

$$\frac{\tau}{\tau_{cr}} = \frac{6,400}{11,300} = .566 \qquad \text{S.F.} = 1.76$$

(15) Neutral Axis Check:

Method I:

$a/b = 96/35 = 2.74$

$Q_{deck} = 1127 \text{ in}^2\text{ft.}$

$I = 46,911 \text{ in}^2\text{ft}^2$

$V = 520.3$ tons

Strake E (Panel just above N.A.)

A platform and its longitudinals = $25.03+8.28 = 33.31 \text{ in}^2$

Q side shell

Strake F	(68")(.375)(21.5-13.88)	= 194
Strake E	(39")(.3437)(1.5)	= 20.1

Q side longitudinals

#12	(1.725) (8.0)	= 13.8
#11	(1.725) (5.5)	= 9.5
Platform	33.31 (16.83-13.89)	= 97.4

Q total = 1127 + 194 + 20.1 + 13.8 + 9.5 + 97.4 = 1462

$$\tau = \frac{VQ}{tI} = \frac{520.3(2240)(1462)}{(.3437)(46,911)} = 10,620 \text{ psi.}$$

$$\tau_{cr} = K_s \frac{\pi^2 D}{tb^2} = 6.2 \frac{\pi^2(111,650)}{(.3437)(35)^2} = 16,200 \text{ psi.}$$

$K_s = 6.2$ (pure shear simply supported)

assume σ very small

$$\frac{\tau}{\tau_{cr}} = \frac{10,620}{16,200} = .657 \qquad \text{S.F.} = 1.52$$

Method II: $a/b = 2.74$

$$\frac{\sigma_i}{\eta} = 26,750,000 \left(\frac{t}{b}\right)^2 K$$

$$K = \sqrt{3}\,(5.34 + 4/(a/b)^2) = \sqrt{3}\,(5.34 + .534) = \sqrt{3}\,(5.87)$$

$$\tau_{cr} = \frac{\sigma_i}{\sqrt{3}} = 26{,}750{,}000 \left(\frac{.3437}{35}\right)^2 (5.87) = 15{,}100 \text{ psi.}$$

$$\frac{\tau}{\tau_{cr}} = \frac{10{,}620}{15{,}100} = .705 \qquad \text{S.F.} = 1.42$$

Part IV - Web Frame Weight

(1) Nomenclature for web frame calculations

A = area

B = maximum breadth of ship

d = depth of beam

h = head of water

l = length as defined in American Bureau of Shipping Rules for Building and Classing Steel Vessels.

M = Frame Numeral, ABS Rules

s = web frame spacing

t = thickness

Subscripts

F = Flange

W = Web

T = Total

(2) Summary of Web Frame Percentage Calculations

	Web Spacing				
Section	5.34	6	8	10	12
3	122	130	155	178.5	202
4	61.6	64	76.9	88	100.8
5	246	270	342	383.0	423.0
6	96	102.5	122.5	141.8	150.8
Total	525.6	566.5	696.4	791.3	876.6
% of 8' spacing	75.5%	81.4%	100%	113.8%	126%

(3) Calculation of Upper Deck Beam

$.025B = .025(41) = 1'.$ $h = 4'$

Using $d = 1'$ Rules require $t = 0.40"$, $l = 14$

$M = .004sl^2h = (.004)(14)^2(4)s = 3.14s$

s	8	6	5.34
M	25.2	18.8	16.8
A_F	2.6	1.4	1.0
A_W	4.8	4.8	4.8
A_T	7.4	6.2	5.8
Vol $21(A_T)$	155	130	122

(4) Calculation of Upper Side Transverse

$h = 8'$ $t = .45"$ web

$M = .0045sl^2h = .0045\ (49)(8)s = 1.405s$

Rules say depth = .25 l. We shall use 1' and increase M accordingly by a length ratio squared.

$$M = \left(\frac{7}{4}\right)^2 1.405s = 4.3s$$

	8	6	5.34
M	34.6	25.8	23
A_F	4.2	2.6	2.3
A_w	5.4	5.4	5.4
A_T	9.6	8.0	7.7
(7 + 1) A_T = Vol.	76.9	64.0	61.6

(5) Calculation of Middle Side Transverse

$l = 9.75 - .3(9) + 3 = 10'$ $h = 16'$ $d = 20"$

$$M = \left(\frac{10}{6.66}\right)^2 (.0045)(100)(16)s = 7.2s(2.25) = 16.2s$$

M	130	97.3	86.5
A_F	11.5	7.2	5.8
A_w	9.0	9.0	9.0
A_T	20.5	16.2	14.8
L=14'-8" A x L= Vol.	342	270	246

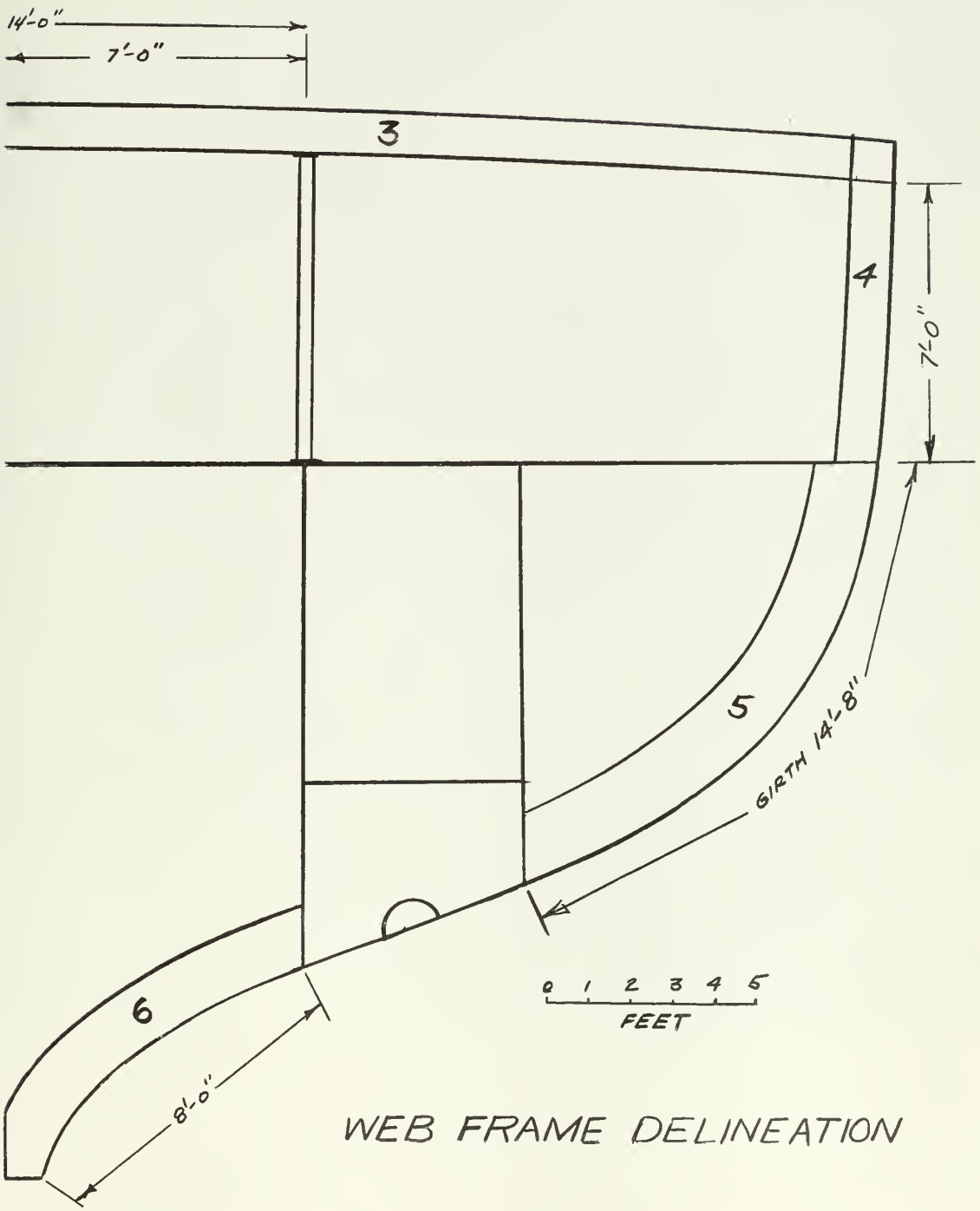
(6) Calculation of Bottom Transverse

$l = 8'$ $t = .47"$ $h = 25'$

$$M = \left(\frac{8}{4}\right)^2(64)(25)s(.0036) = 4(5.77s) = 23s$$

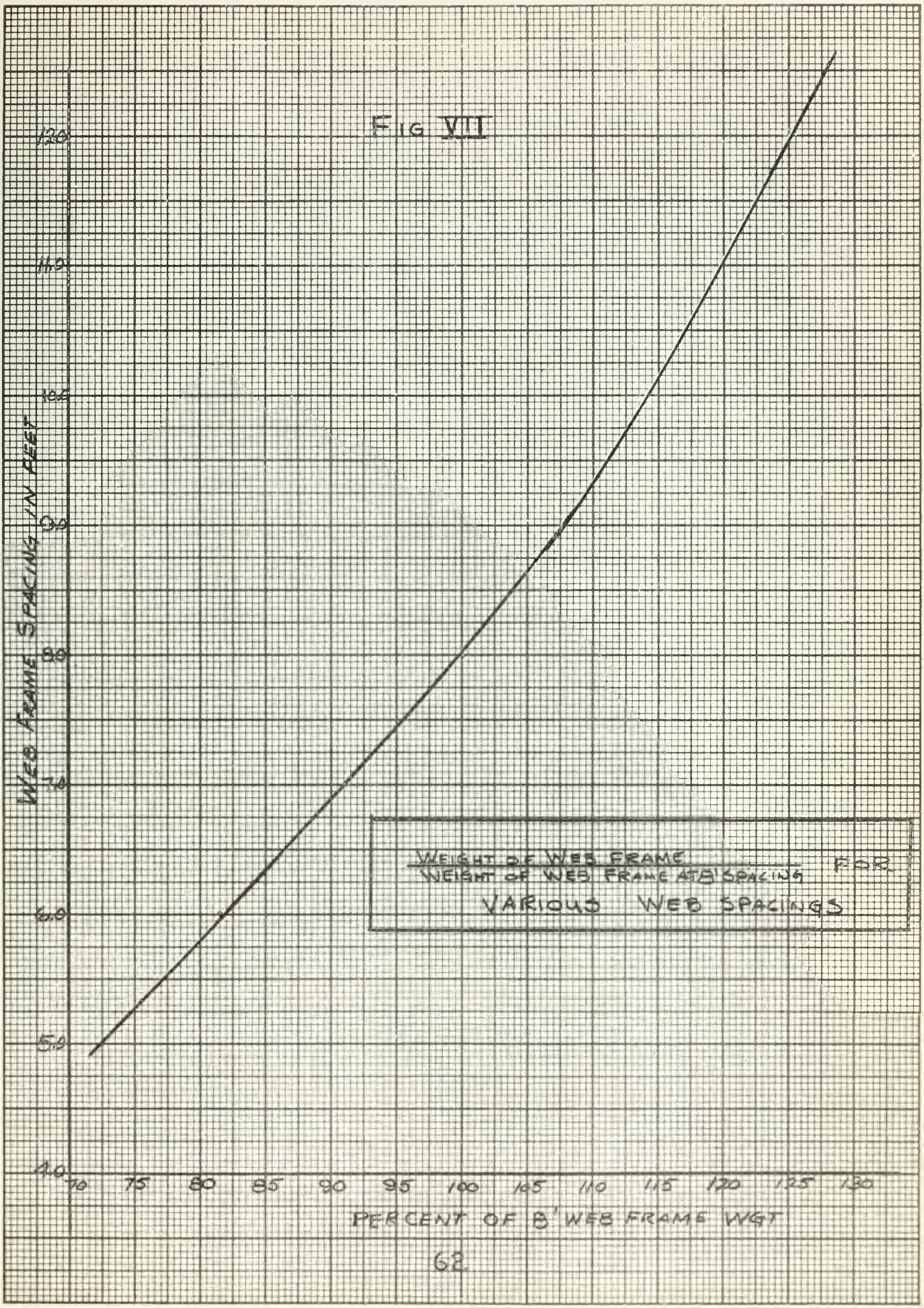
M	82.1	61.6	54.9
A_F	6.8	4.3	3.5
A_w	8.5	8.5	8.5
A_T	15.3	12.8	12.0
Vol.	122.5	102.5	96.0

FIGURE - VI



WEB FRAME DELINEATION

FIG VII


12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
WEB FRAME SPACING IN FEET
70
75
80
85
90
95
100
105
110
115
120
125
130
PERCENT OF 8' WEB FRAME WGT
WEIGHT OF WEB FRAME
WEIGHT OF WEB FRAME AT 8' SPACING
FOR
VARIOUS WEB SPACINGS

APPENDIX B

SUMMARY OF DESIGNED SECTIONS

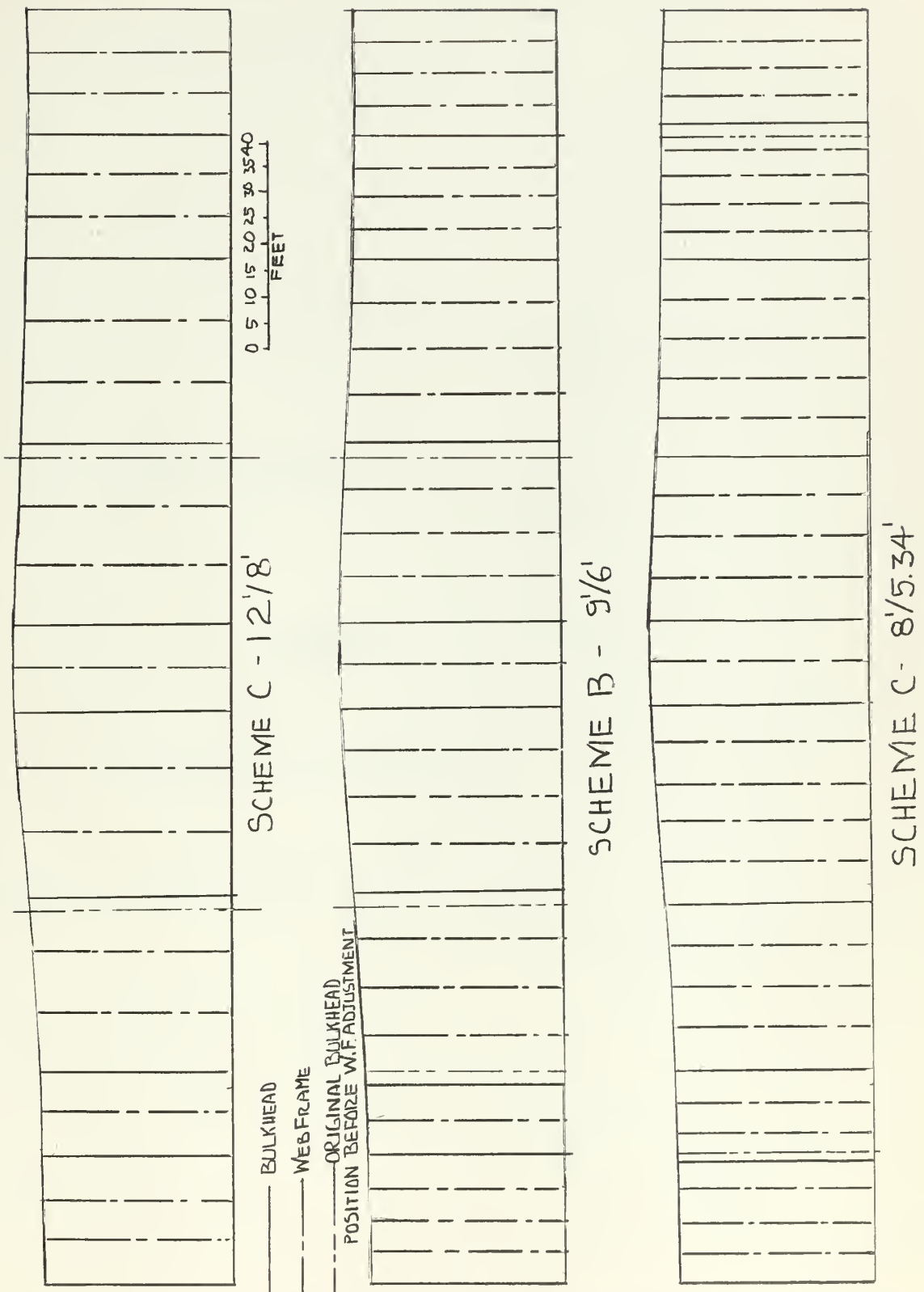
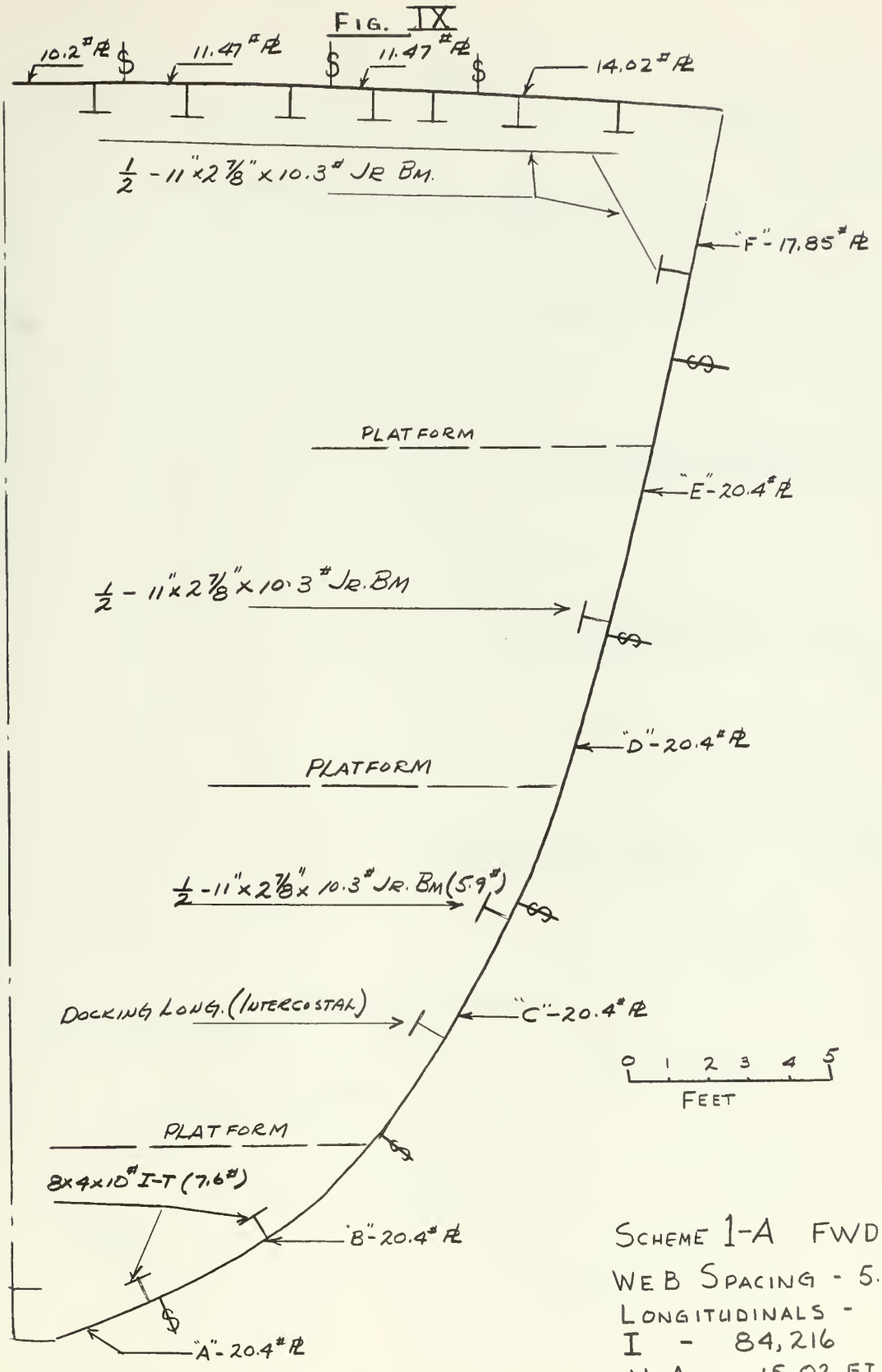


FIGURE VIII SHELL EXPANSIONS - SHOWING WEB FRAME ARRANGEMENTS

FIG. IX



SCHEME 1-A FWD.

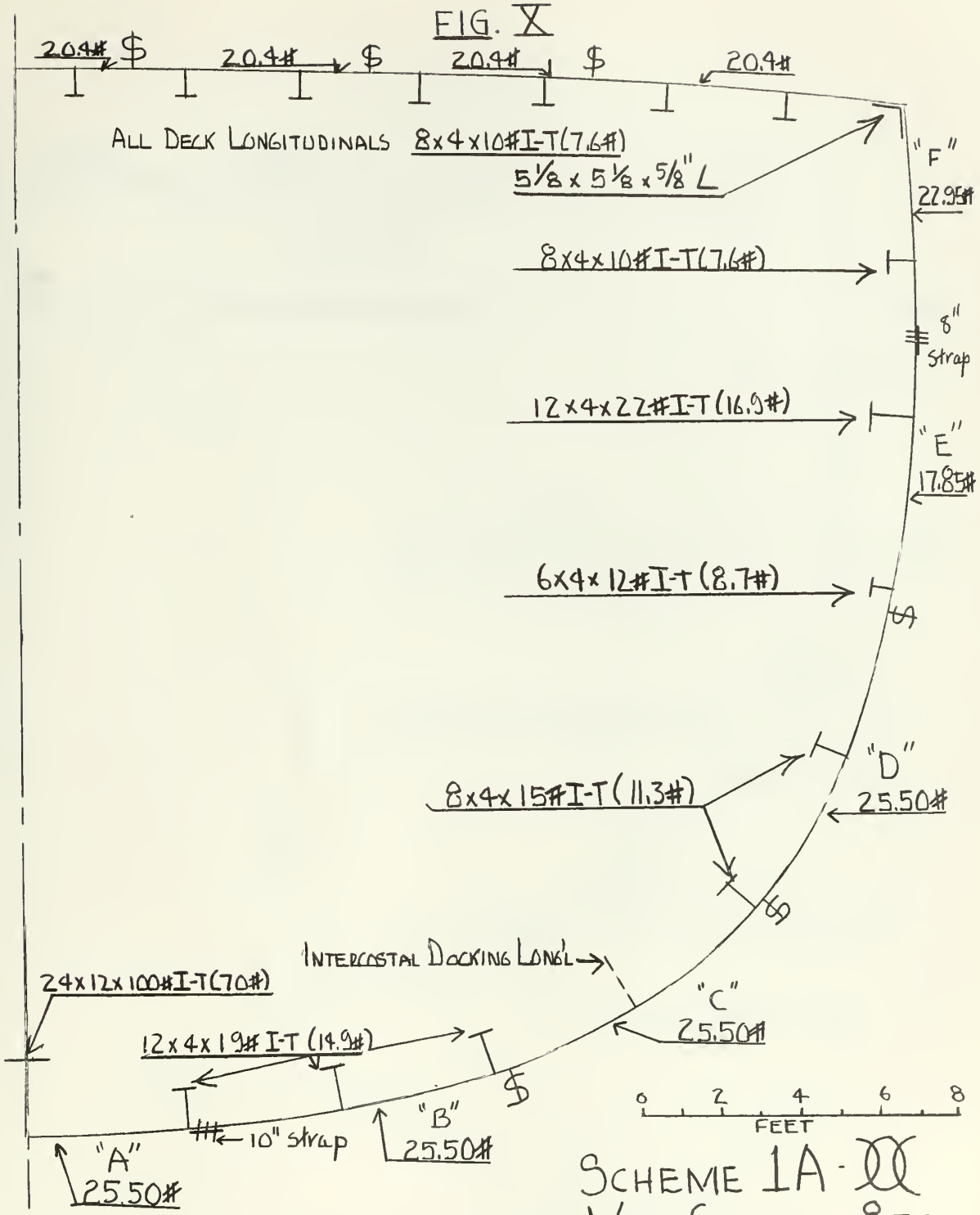
WEB SPACING - 5.34 FT

LONGITUDINALS - 9

I - 84,216

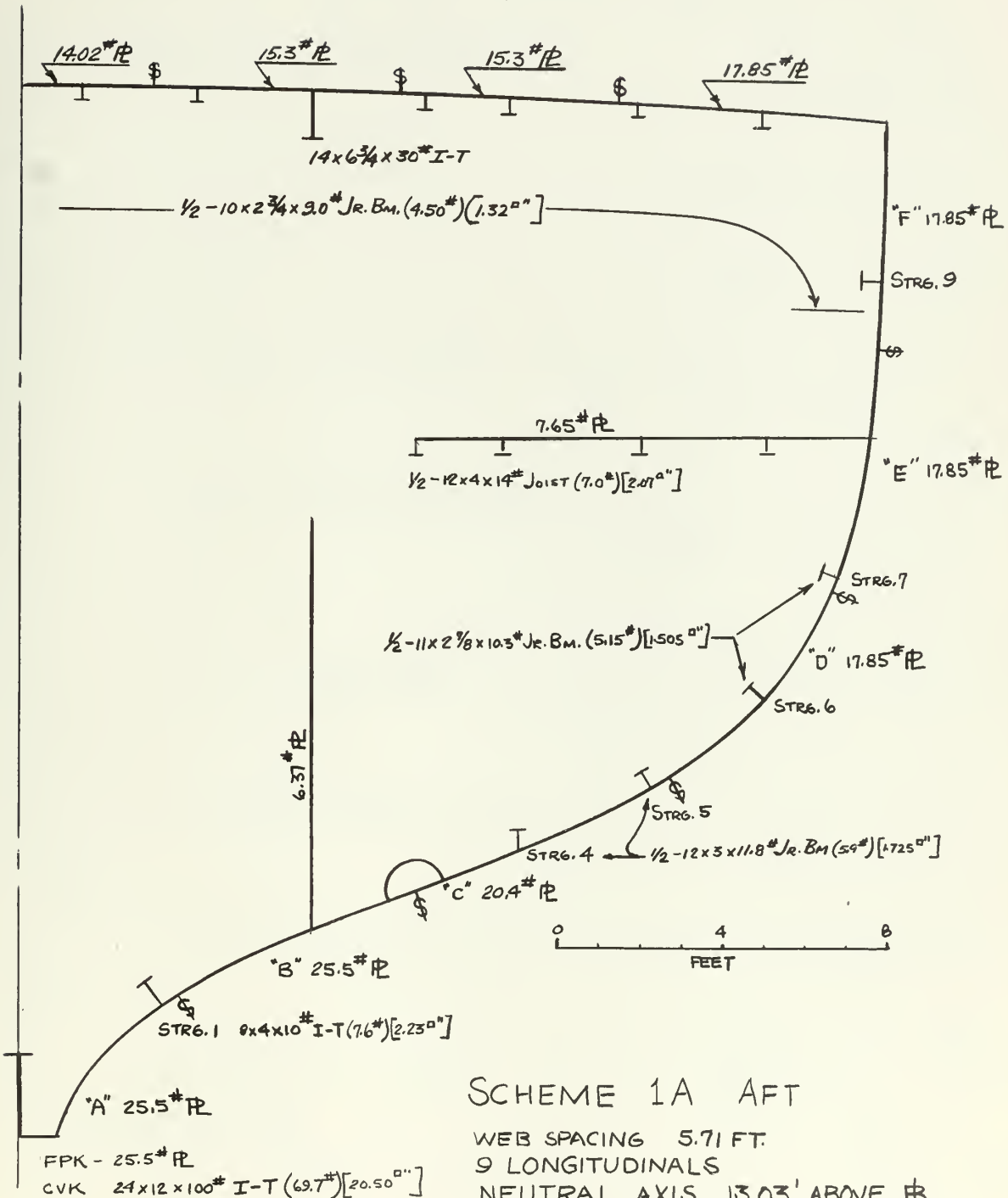
N. A. - 15.02 FT ABOVE ℄

FIG. X



SCHEME 1A - XX
WEB SPACING 8 FT
9 LONGITUDINALS
N.A. 12.44' ABOVE BL
I = 112,853 ft²-in²

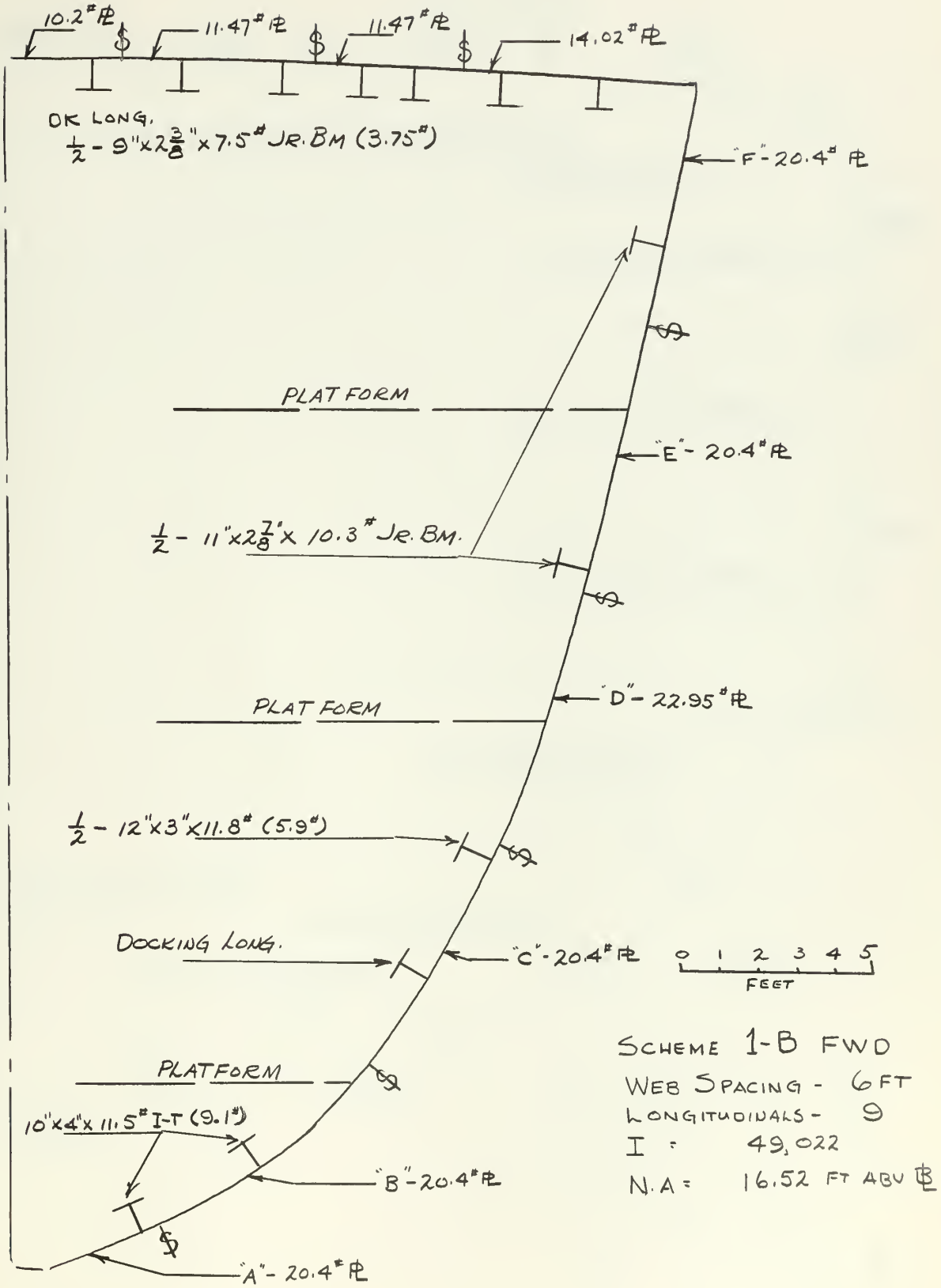
FIG XI



SCHEME 1A AFT

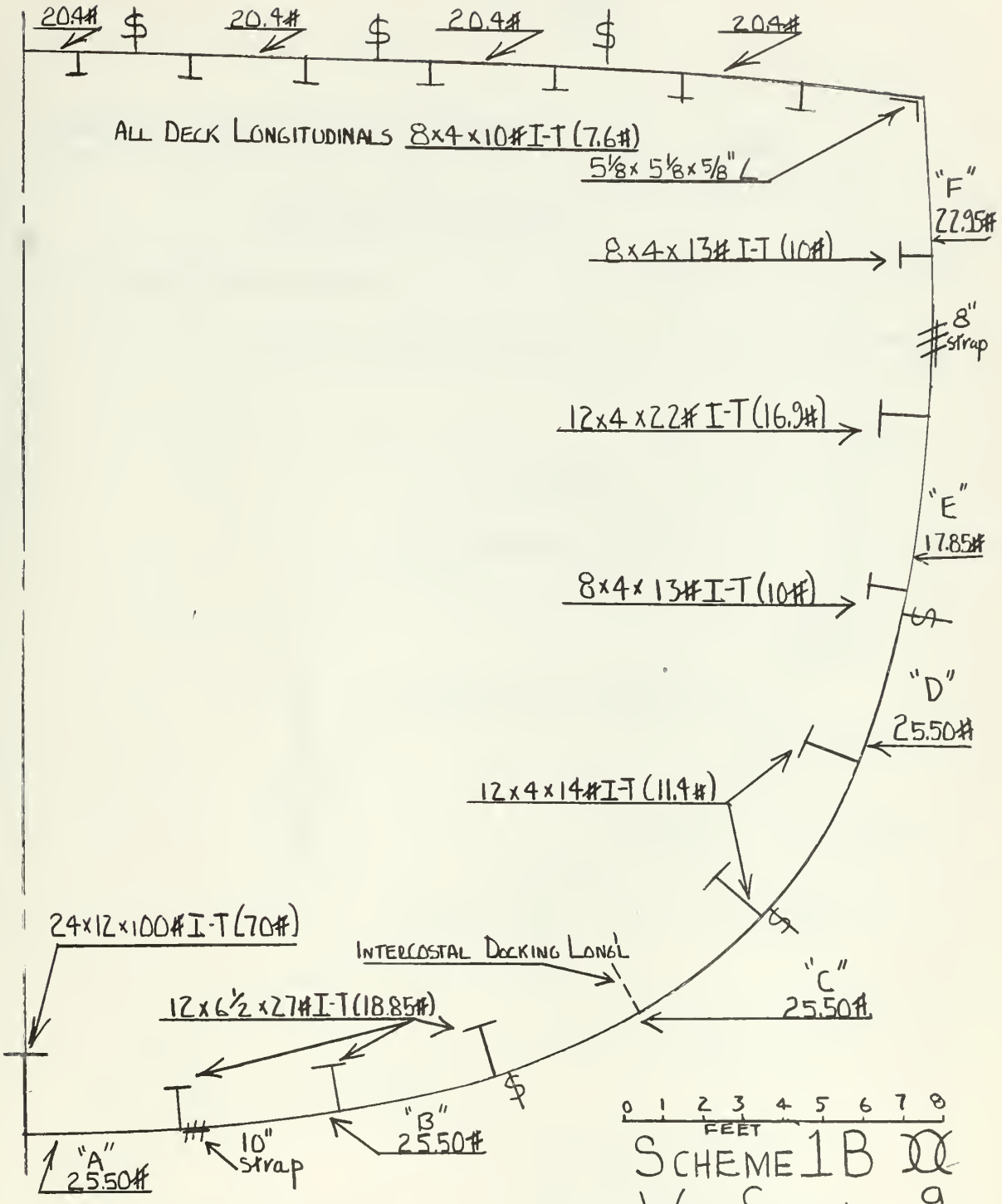
WEB SPACING 5.71 FT.
9 LONGITUDINALS
NEUTRAL AXIS 13.03' ABOVE ℄
MOMENT OF INERTIA 53,120 Ft²-□"

FIG-XII



SCHEME 1-B FWD
WEB SPACING - 6 FT
LONGITUDINALS - 9
I = 49,022
N.A = 16.52 FT ABV ℄

FIG-XIII



SCHEME 1B

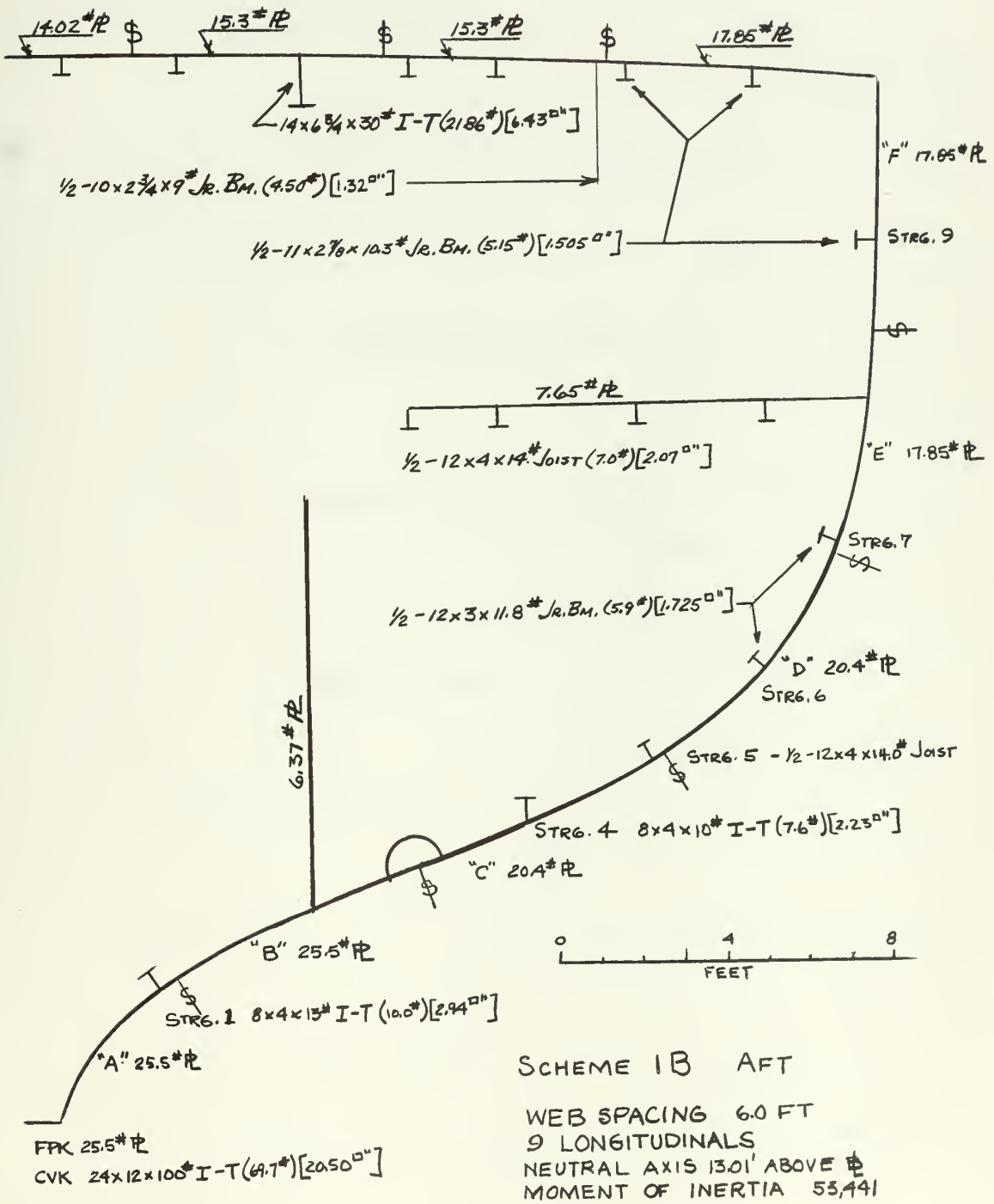
WEB SPACING = 9 FT

9 LONGITUDINALS

N.A. 12.49' ABOVE ℄

$I = 113,230 \text{ FT}^2\text{IN}^2$

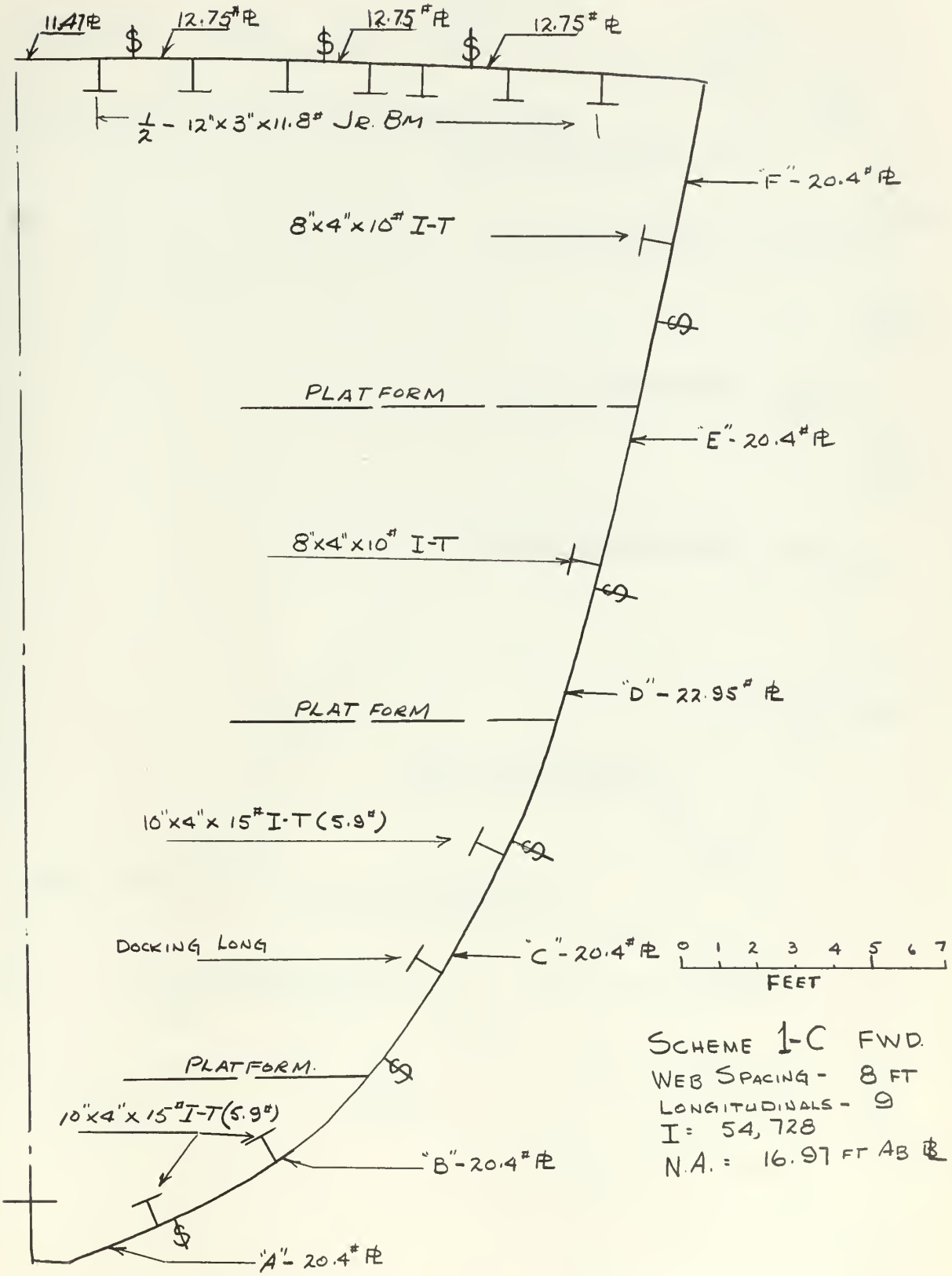
FIG. XIV



SCHEME 1B AFT

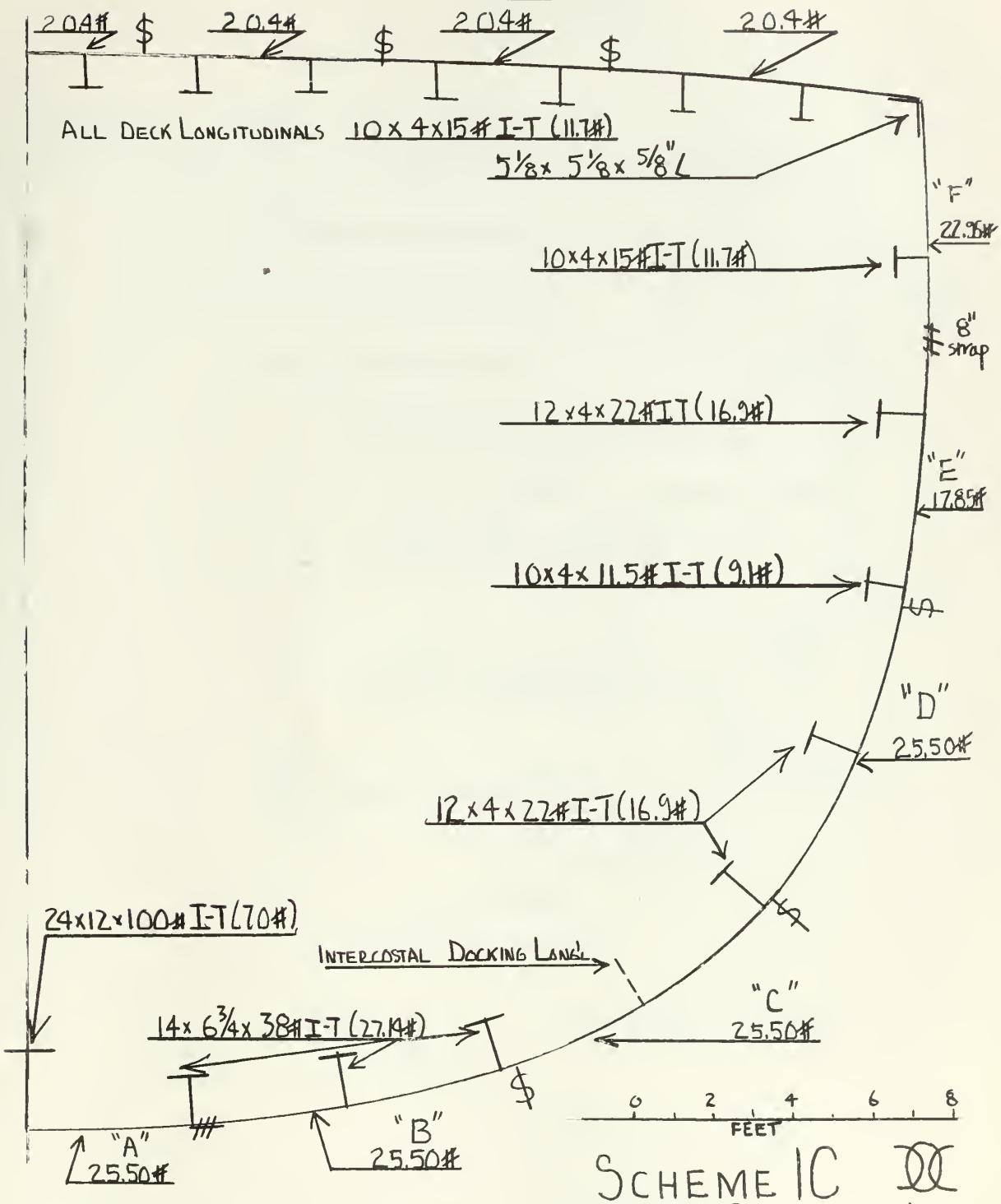
WEB SPACING 6.0 FT
9 LONGITUDINALS
NEUTRAL AXIS 13.01' ABOVE ℄
MOMENT OF INERTIA 53,441

FIG-XV



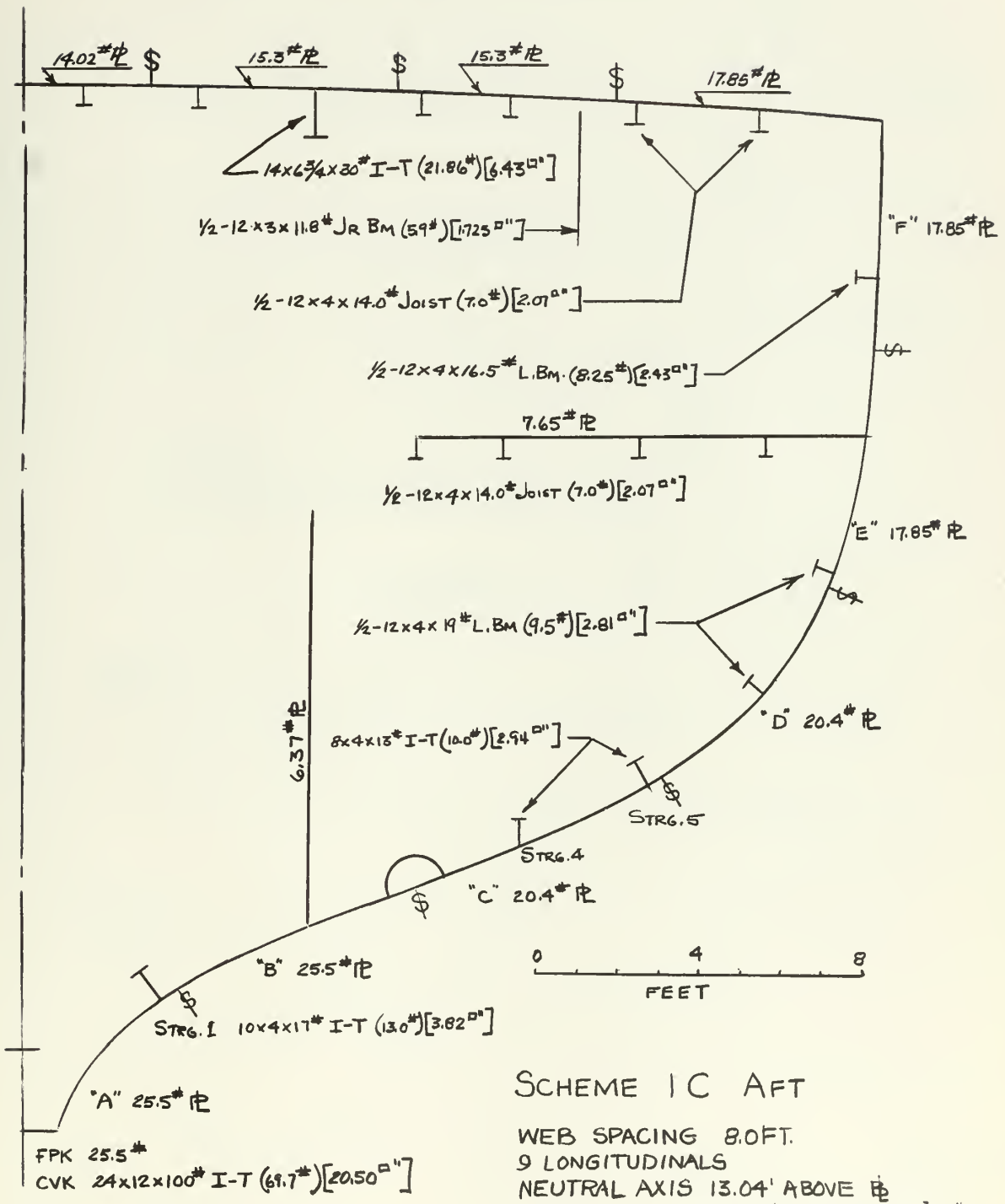
SCHEME 1-C FWD.
WEB SPACING - 8 FT
LONGITUDINALS - 9
I = 54,728
N.A. = 16.97 FT AB ℄

FIG-XVI



SCHEME IC
WEB SPACING 12 FT.
9 LONGITUDINALS
N.A. 12.64' ABOVE ℄
I = 113,186 FT² IN²

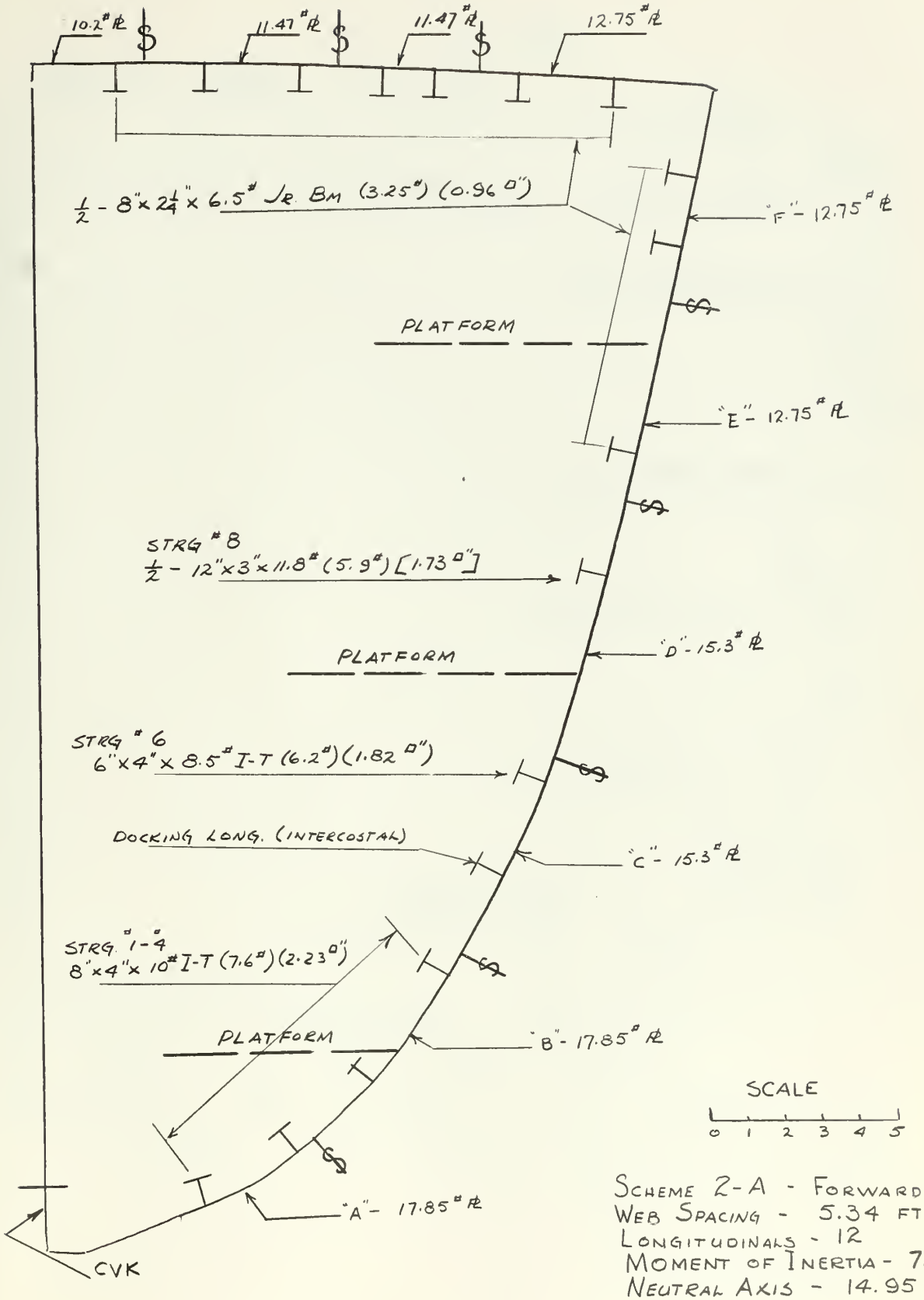
FIG - XVII



SCHEME 1C AFT

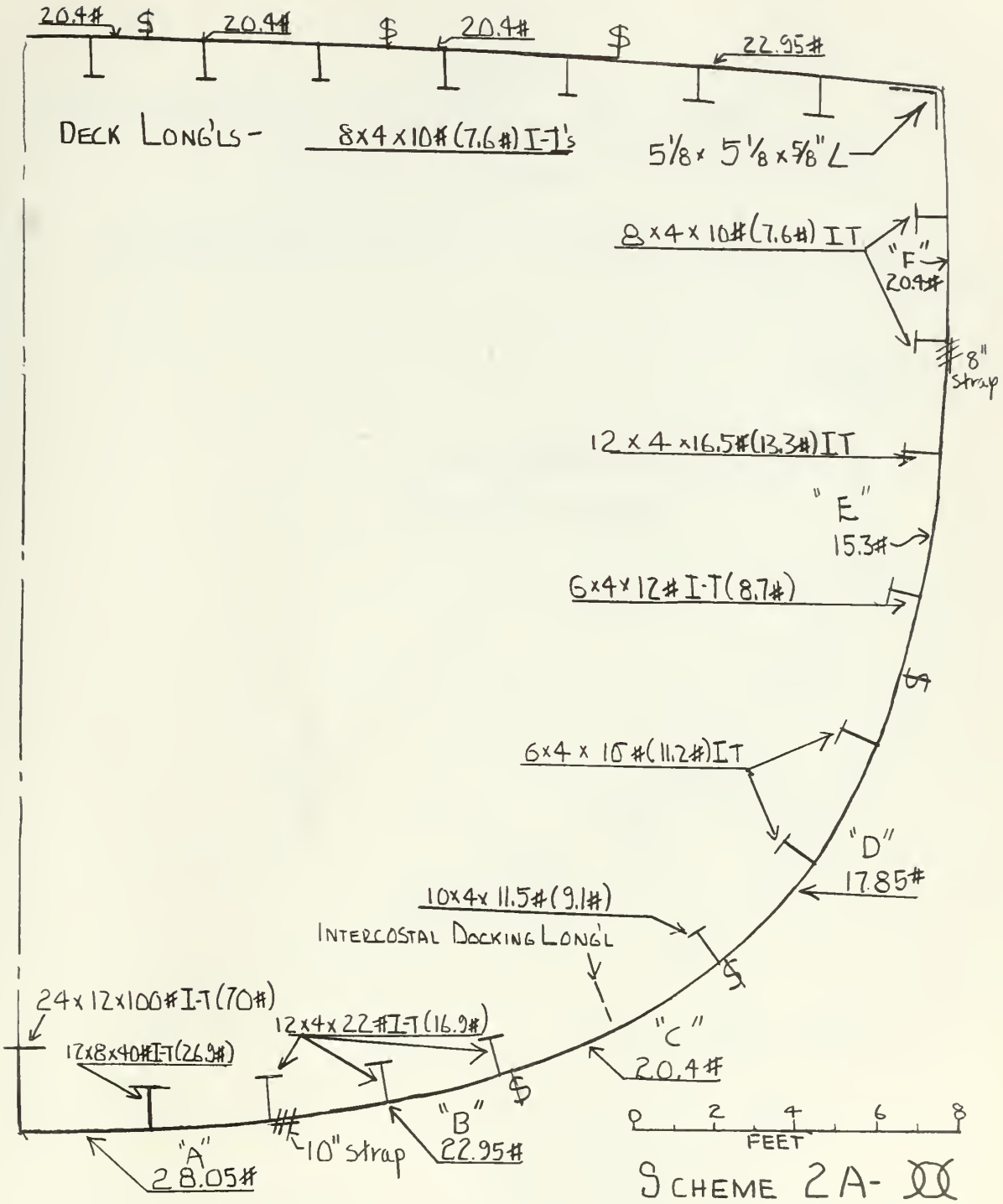
WEB SPACING 8.0FT.
9 LONGITUDINALS
NEUTRAL AXIS 13.04' ABOVE ℄
MOMENT OF INERTIA 54,418 Ft²-□"

FIG-XVIII



SCHEME 2-A - FORWARD
WEB SPACING - 5.34 FT
LONGITUDINALS - 12
MOMENT OF INERTIA - 71,911
NEUTRAL AXIS - 14.95 FT

FIG-XIX



SCHEME 2A-

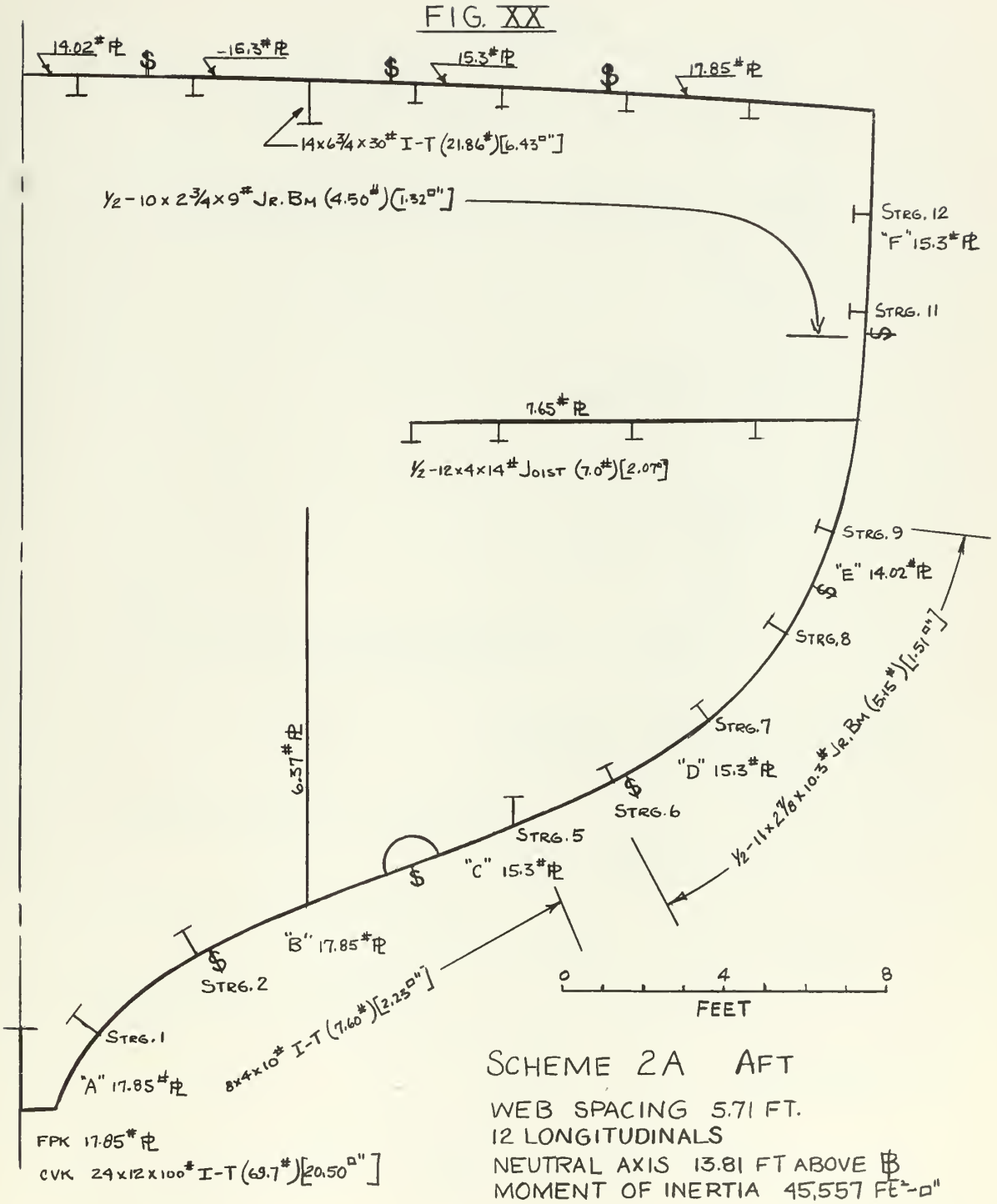
WEB SPACING 8 FT.

12 LONGITUDINALS

N.A. 12.99' ABOVE BL

I = 110,058 ft²-in²

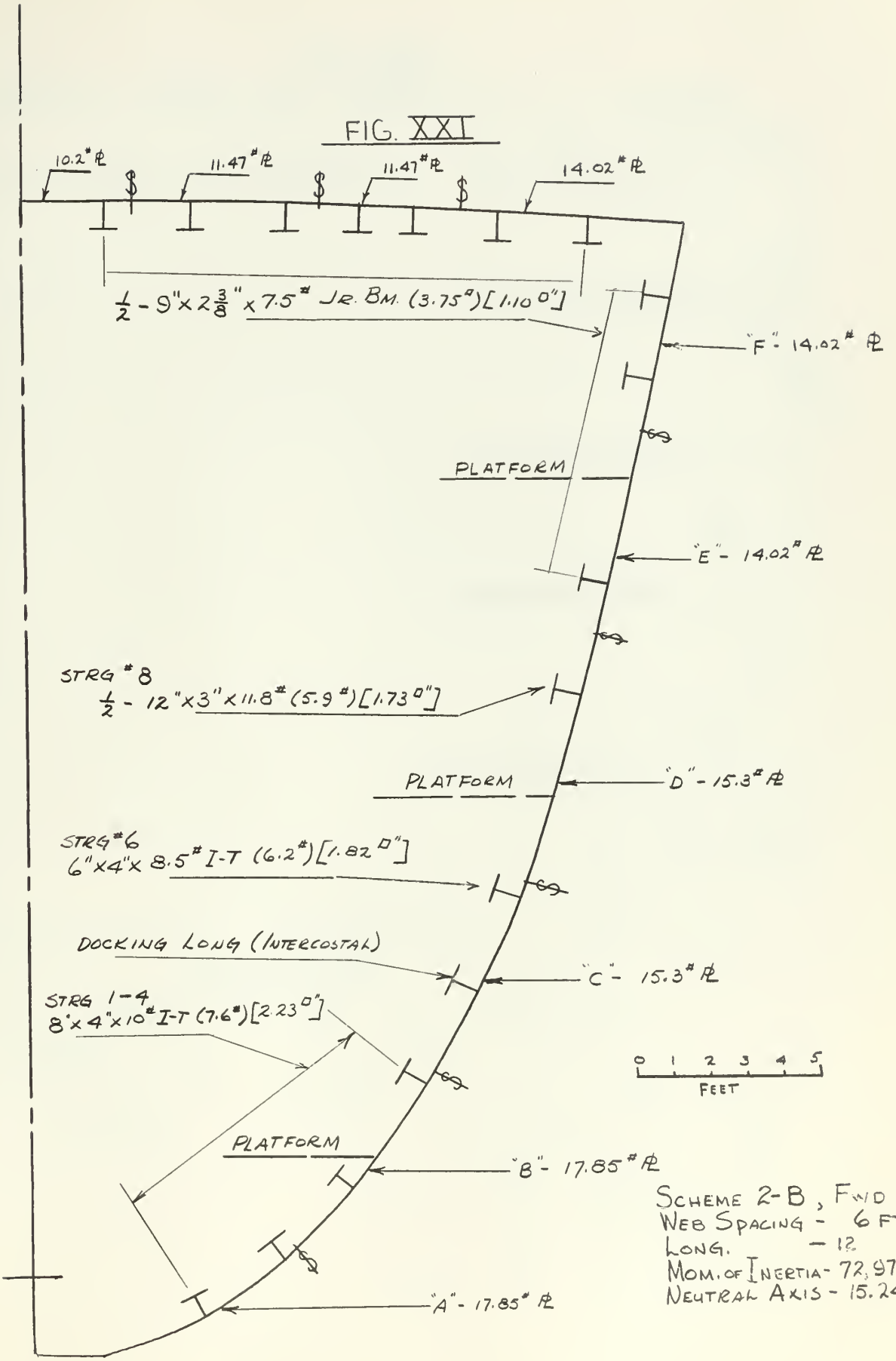
FIG. XX



SCHEME 2A AFT

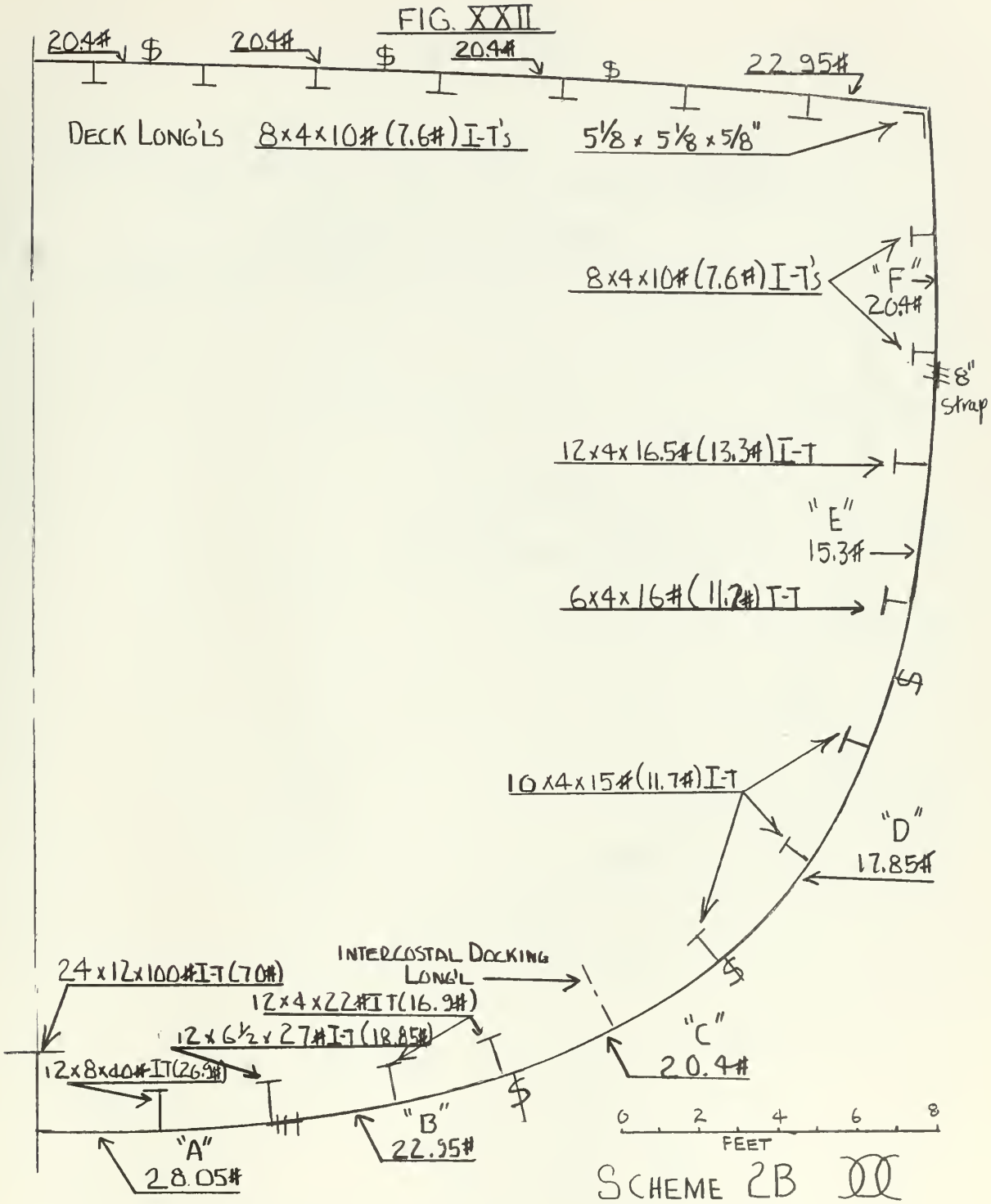
WEB SPACING 5.71 FT.
12 LONGITUDINALS
NEUTRAL AXIS 13.81 FT ABOVE ℔
MOMENT OF INERTIA 45,557 FT²-□"

FIG. XXI



SCHEME 2-B, F.W.D.
WEB SPACING - 6 FT
LONG. - 12
MOM. OF INERTIA - 72,970
NEUTRAL AXIS - 15.24

FIG. XXII



SCHEME 2B

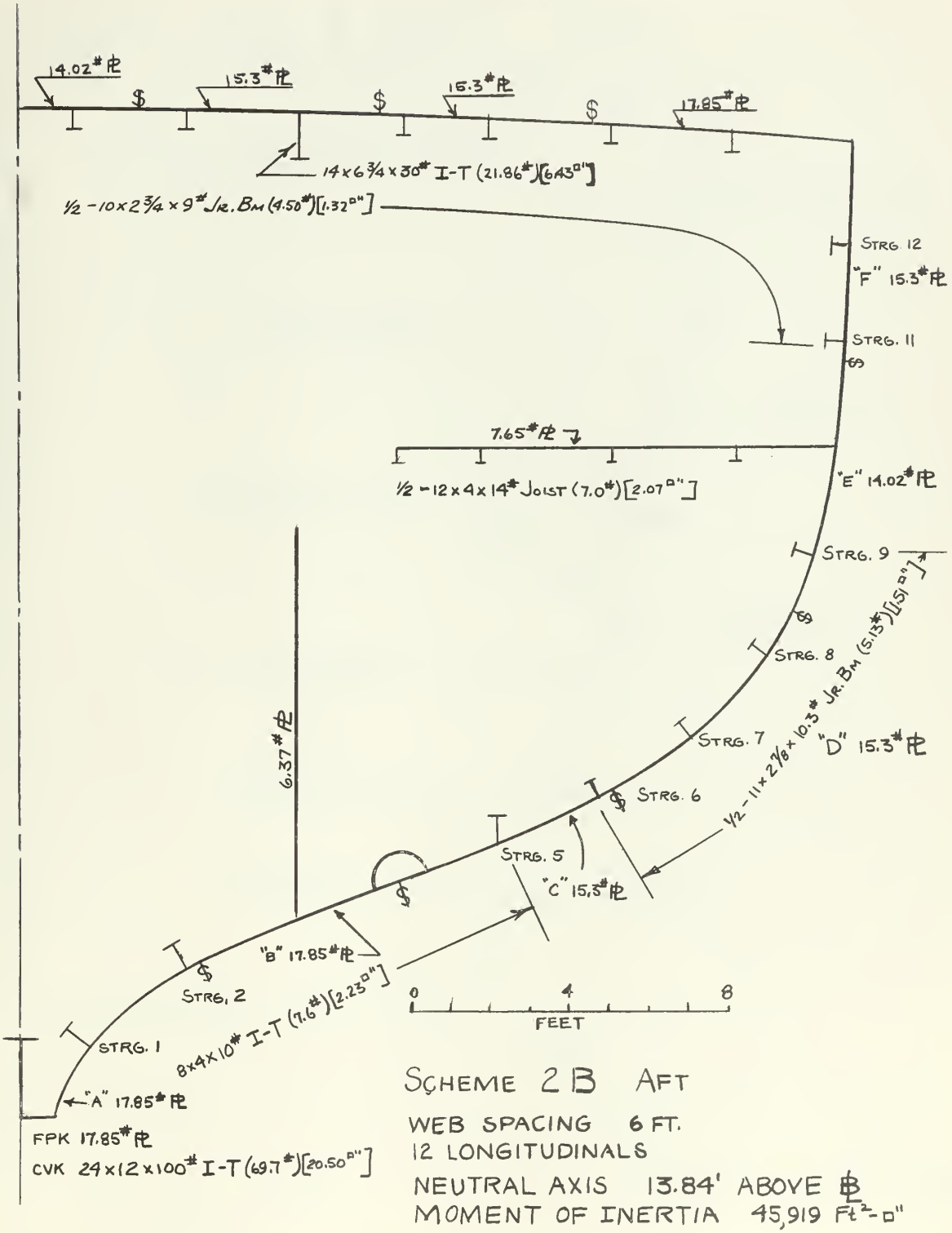
WEB SPACING 9 FT.

12 LONGITUDINALS

N.A. 12.91' ABOVE ℄

$I = 109,900$ FT²-in²

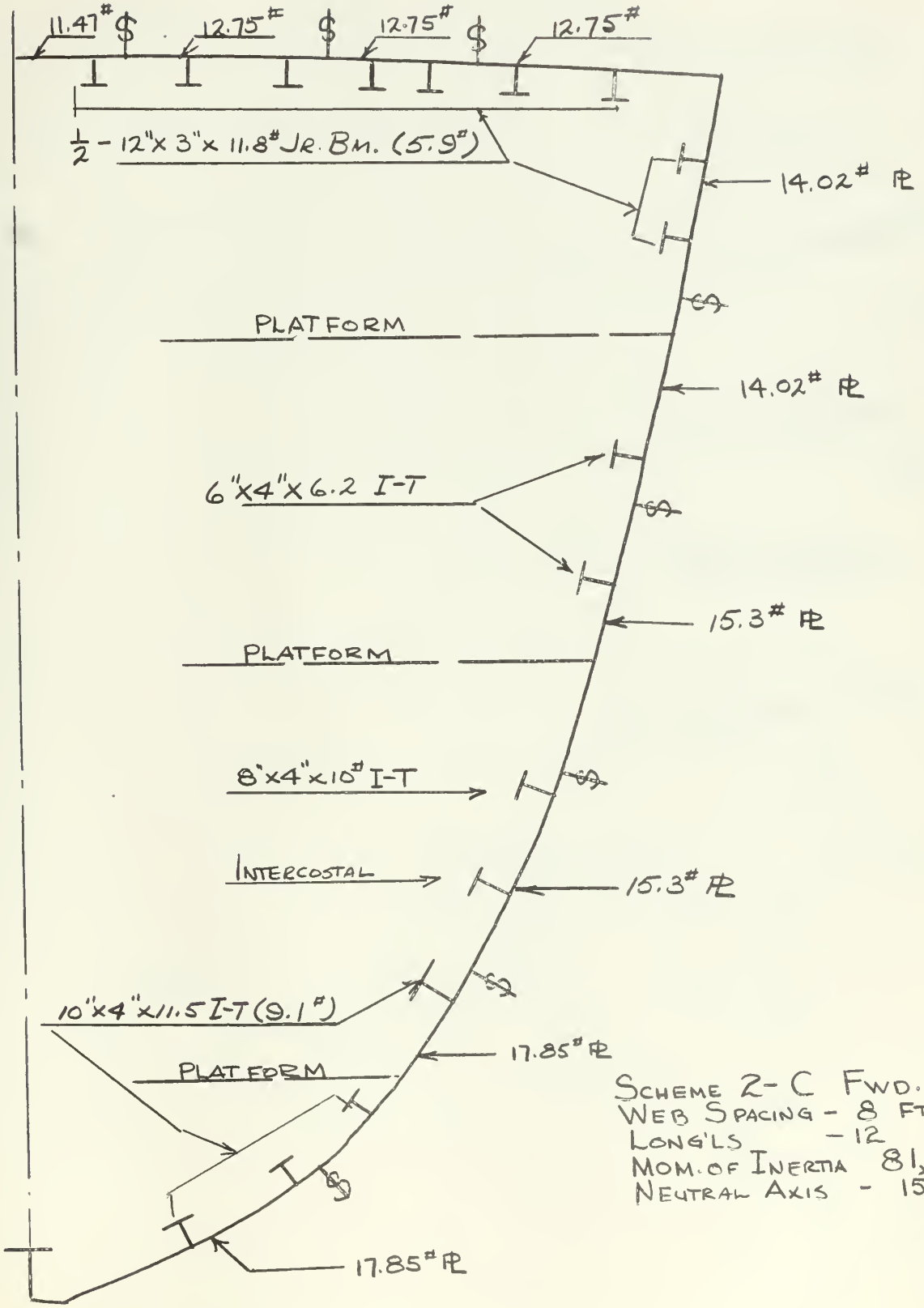
FIG. XXIII



SCHEME 2B AFT

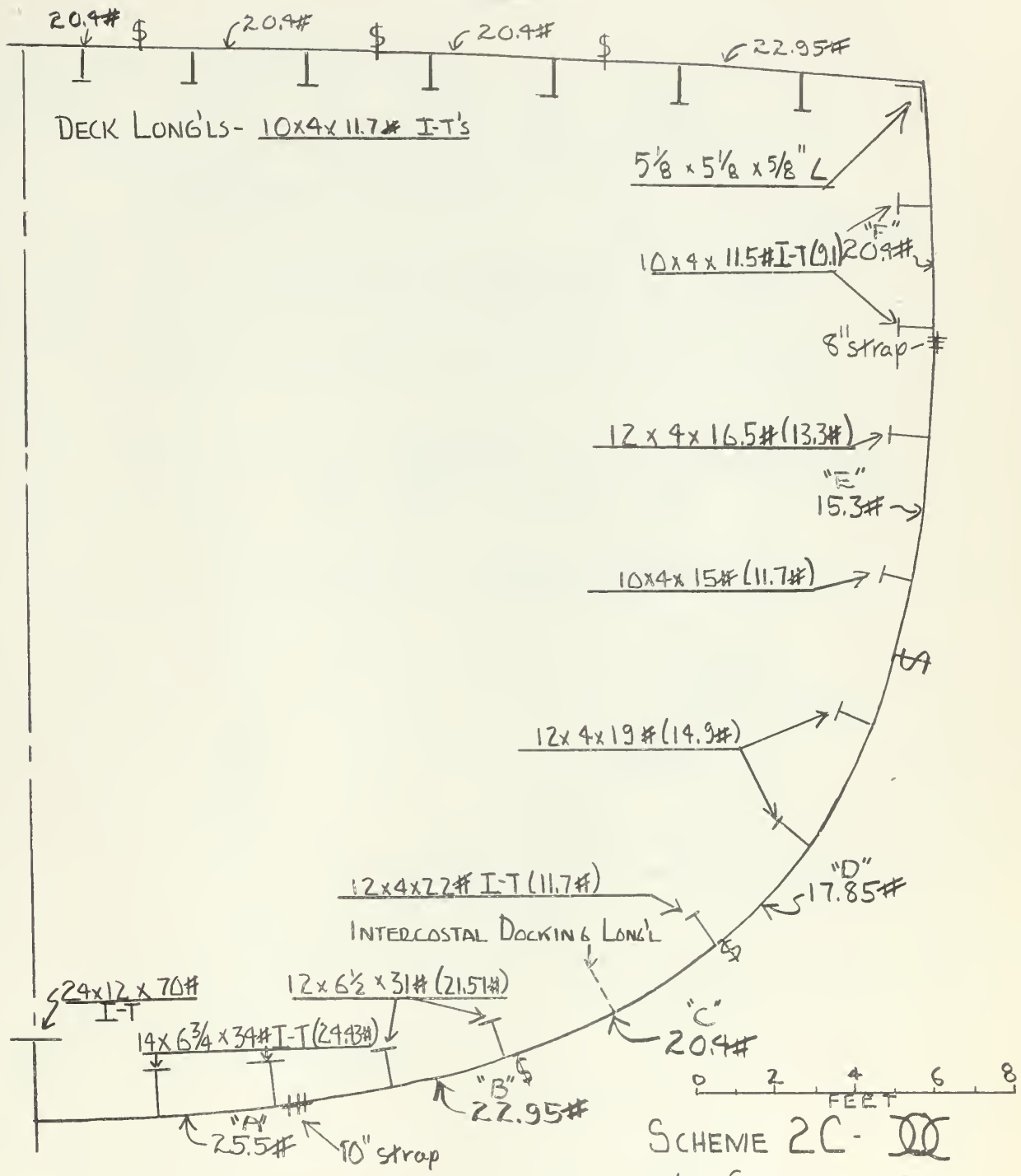
WEB SPACING 6 FT.
12 LONGITUDINALS
NEUTRAL AXIS 13.84' ABOVE ℄
MOMENT OF INERTIA 45,919 Ft²-□"

FIG. XXIV



SCHEME 2-C FWD.
WEB SPACING - 8 FT
LONG'LS - 12
MOM. OF INERTIA 81,372
NEUTRAL AXIS - 15.77 FT

FIG. XXV



SCHEME 2C-

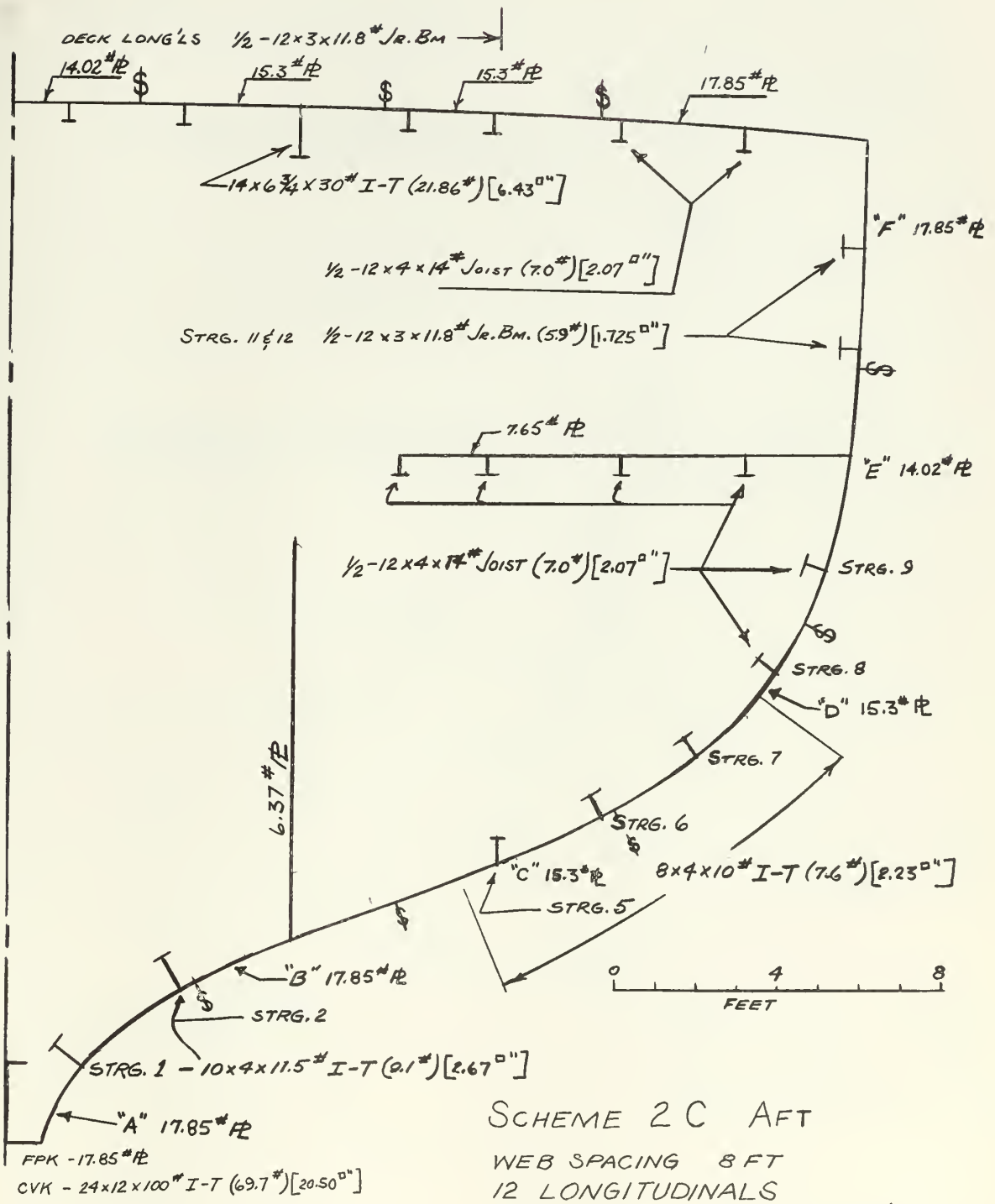
WEB SPACING 12 FT.

12 LONGITUDINALS

N.A. 12.91' ABOVE ℄

$I = 109,773$ ft²-in²

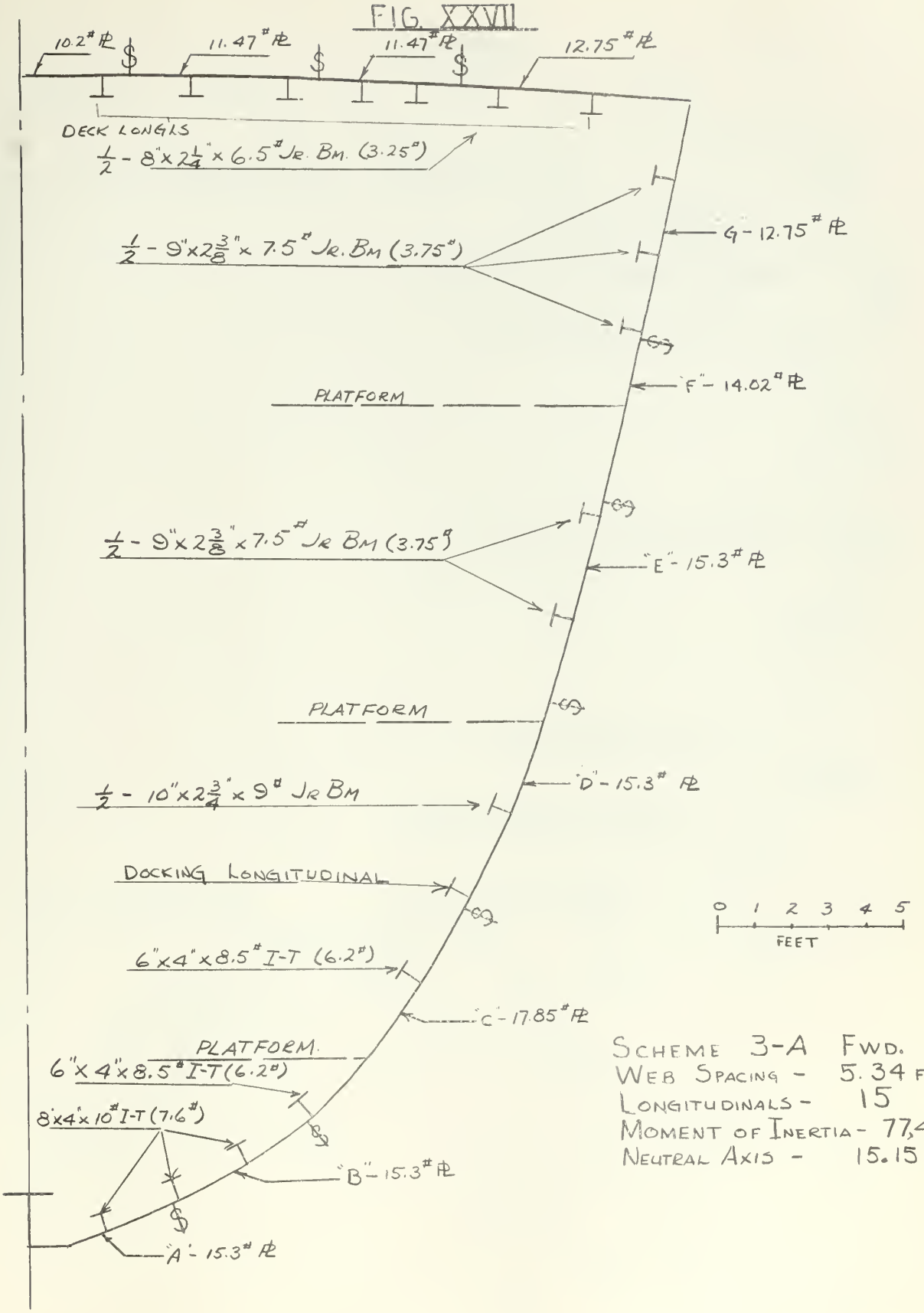
FIG. XXVI



SCHEME 2 C AFT

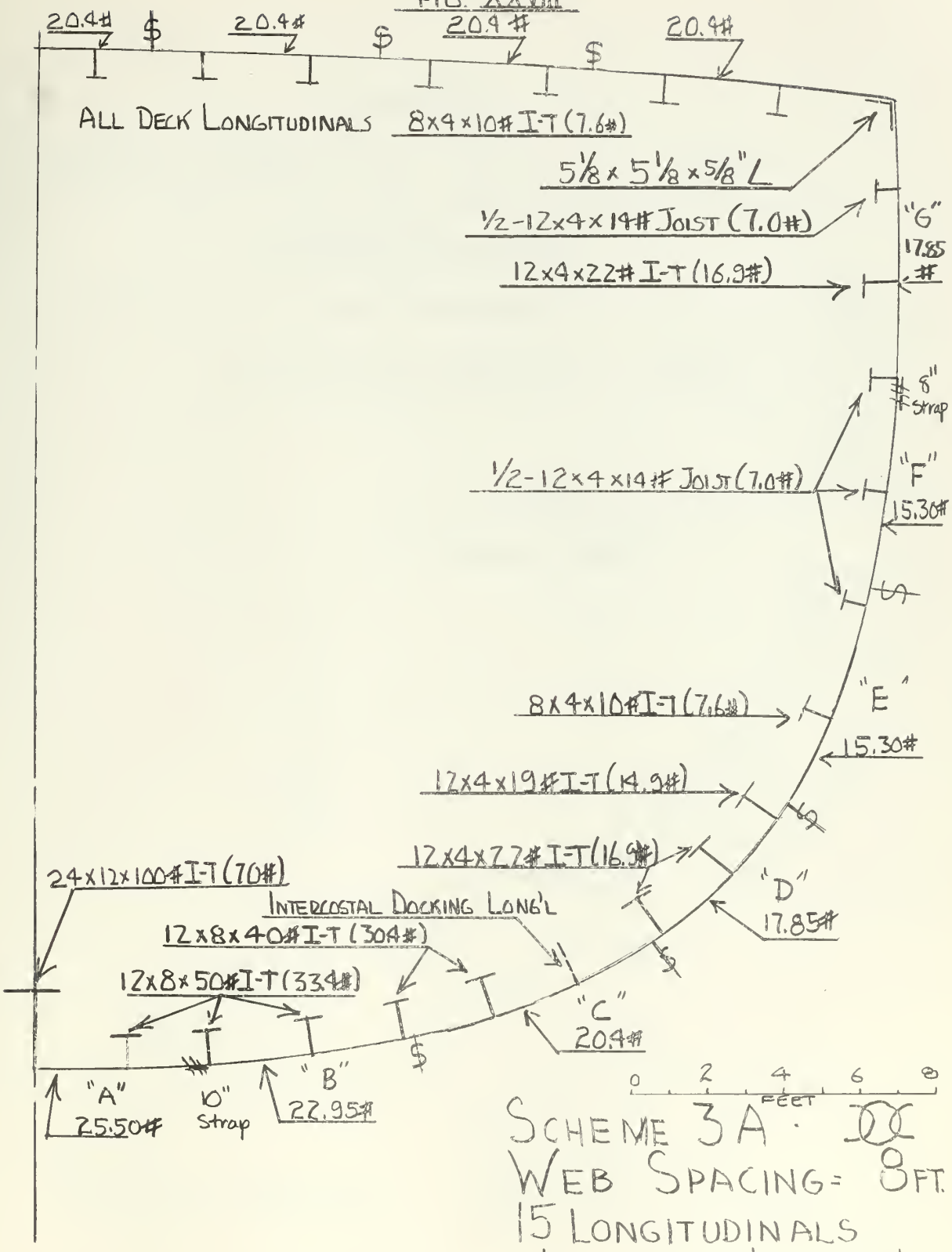
WEB SPACING 8 FT
12 LONGITUDINALS
NEUTRAL AXIS 13.89' ABOVE ℄
MOMENT OF INERTIA = 46,991 Ft²-□"

FIG. XXVII



SCHEME 3-A FWD.
WEB SPACING - 5.34 FT.
LONGITUDINALS - 15
MOMENT OF INERTIA - 77,468
NEUTRAL AXIS - 15.15 FT.

FIG. XXVIII



SCHEME 3A

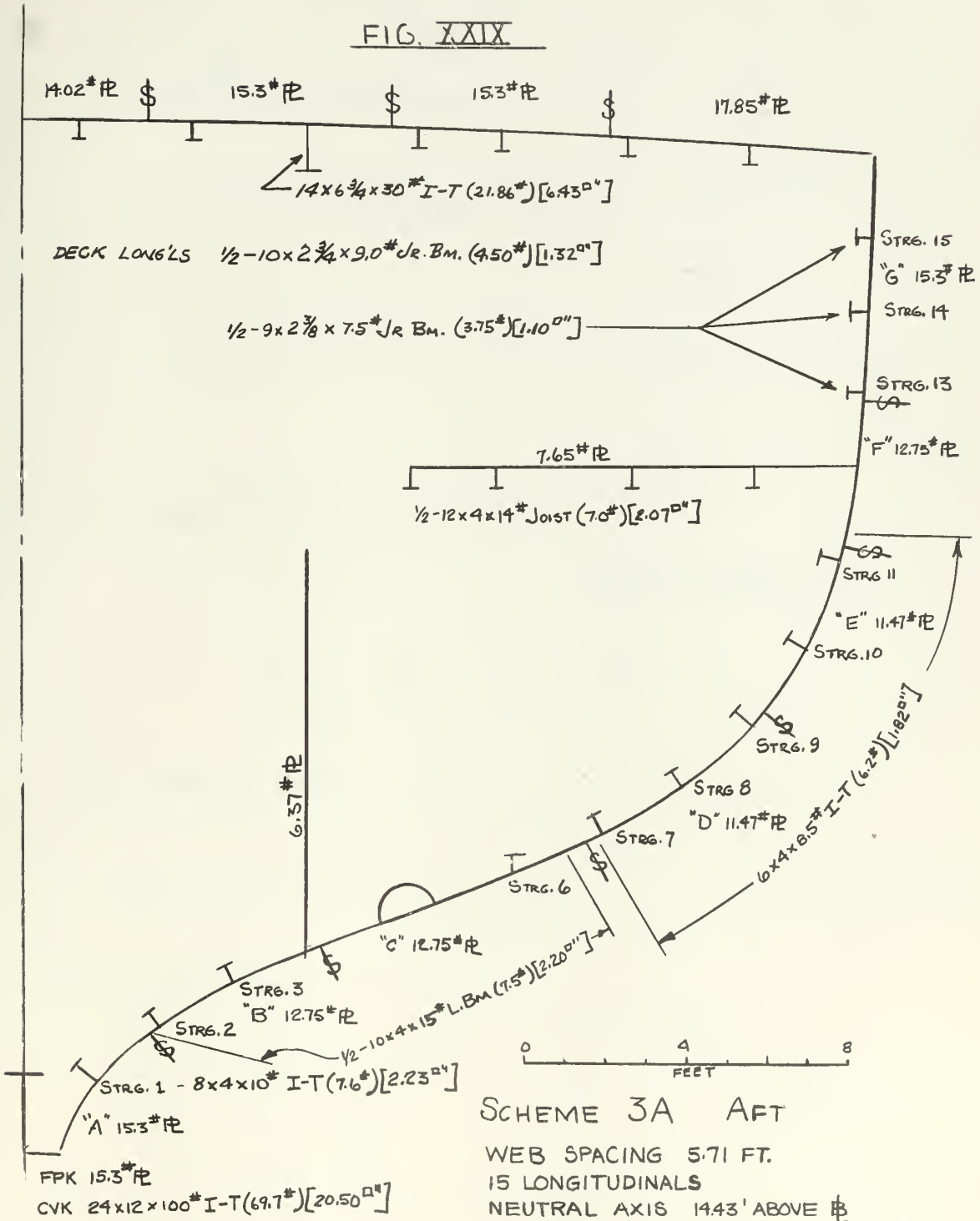
WEB SPACING = 8 FT.

15 LONGITUDINALS

NA - 12.25' ABOVE BL

$I = 103,846 \text{ Ft}^2 \text{ in}^2$

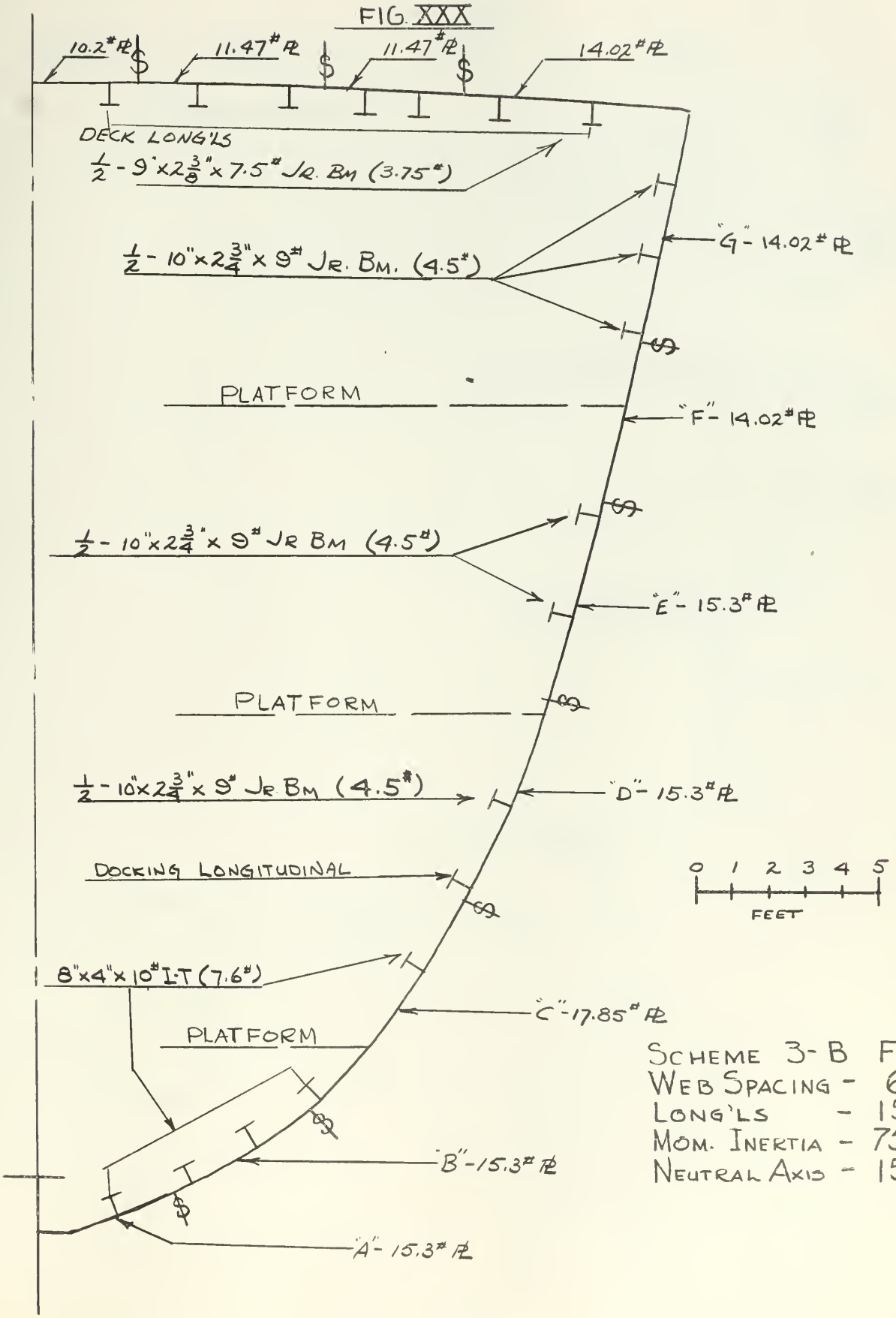
FIG. XXIX



SCHEME 3A AFT

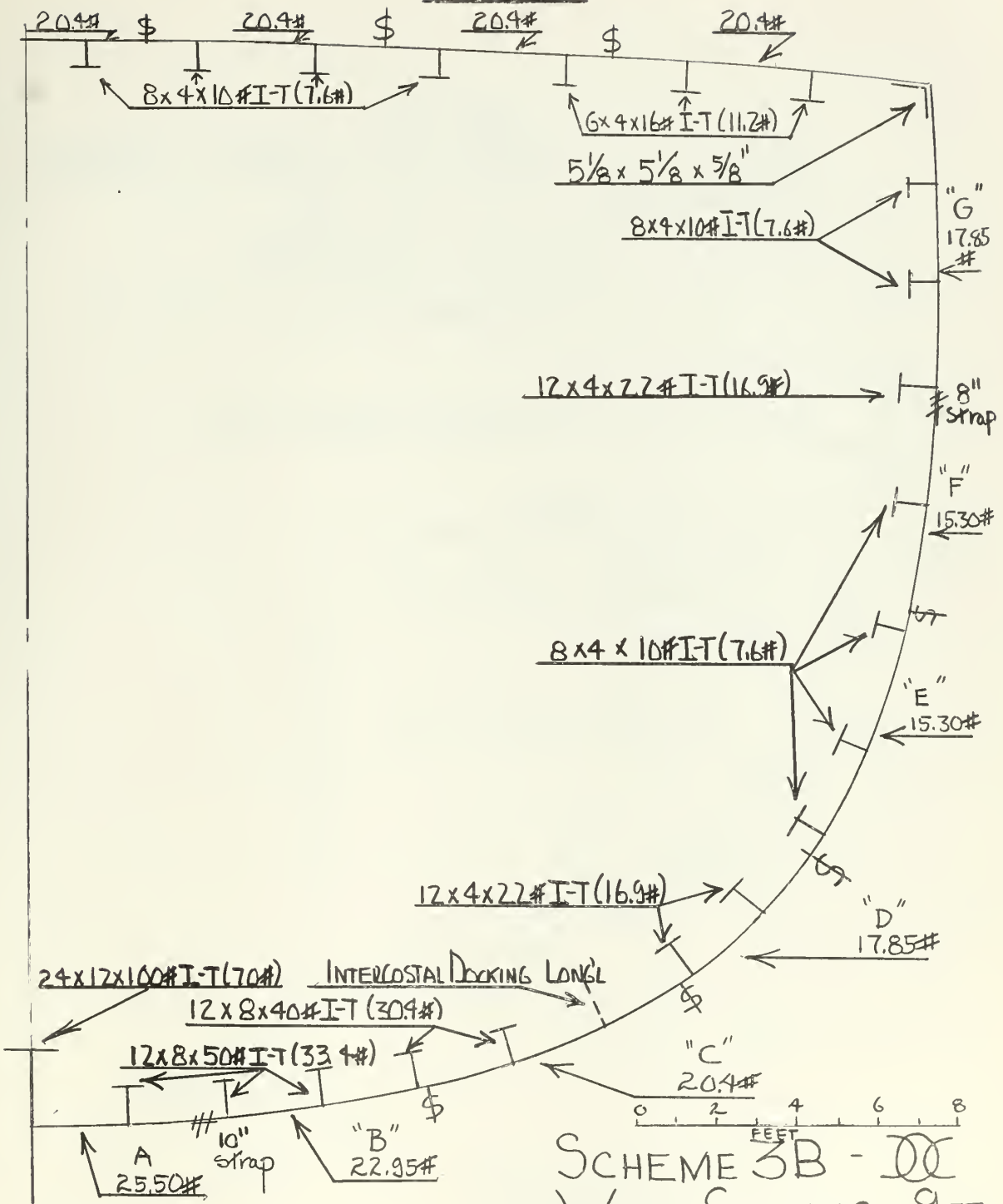
WEB SPACING 5.71 FT.
15 LONGITUDINALS
NEUTRAL AXIS 14.43' ABOVE ℄
MOMENT OF INERTIA 43,554 Ft²-□'

FIG. XXX



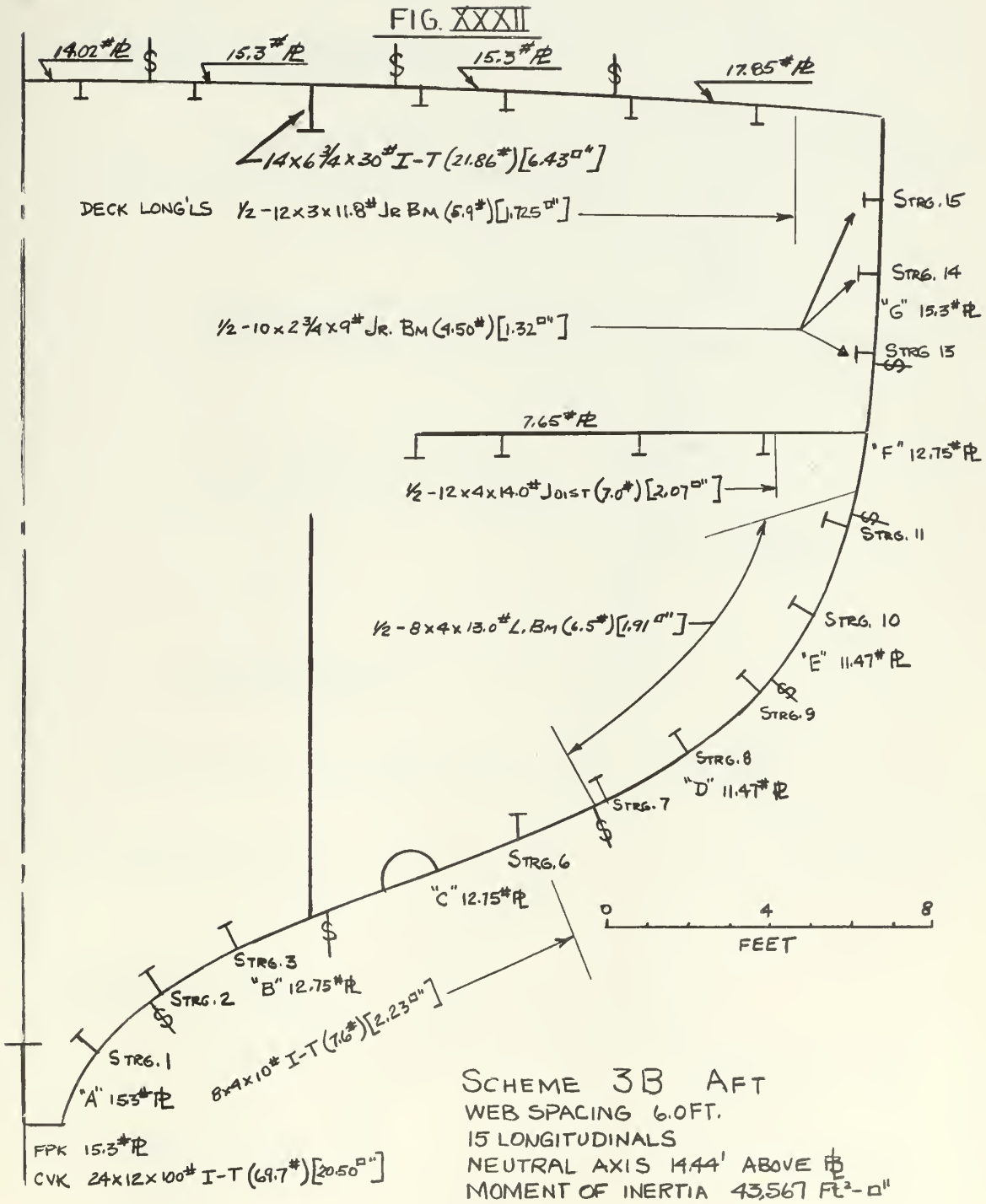
SCHEME 3-B FWD
WEB SPACING - 6 FT
LONG'LS - 15
MOM. INERTIA - 75,705
NEUTRAL AXIS - 15.27

FIG. XXXI



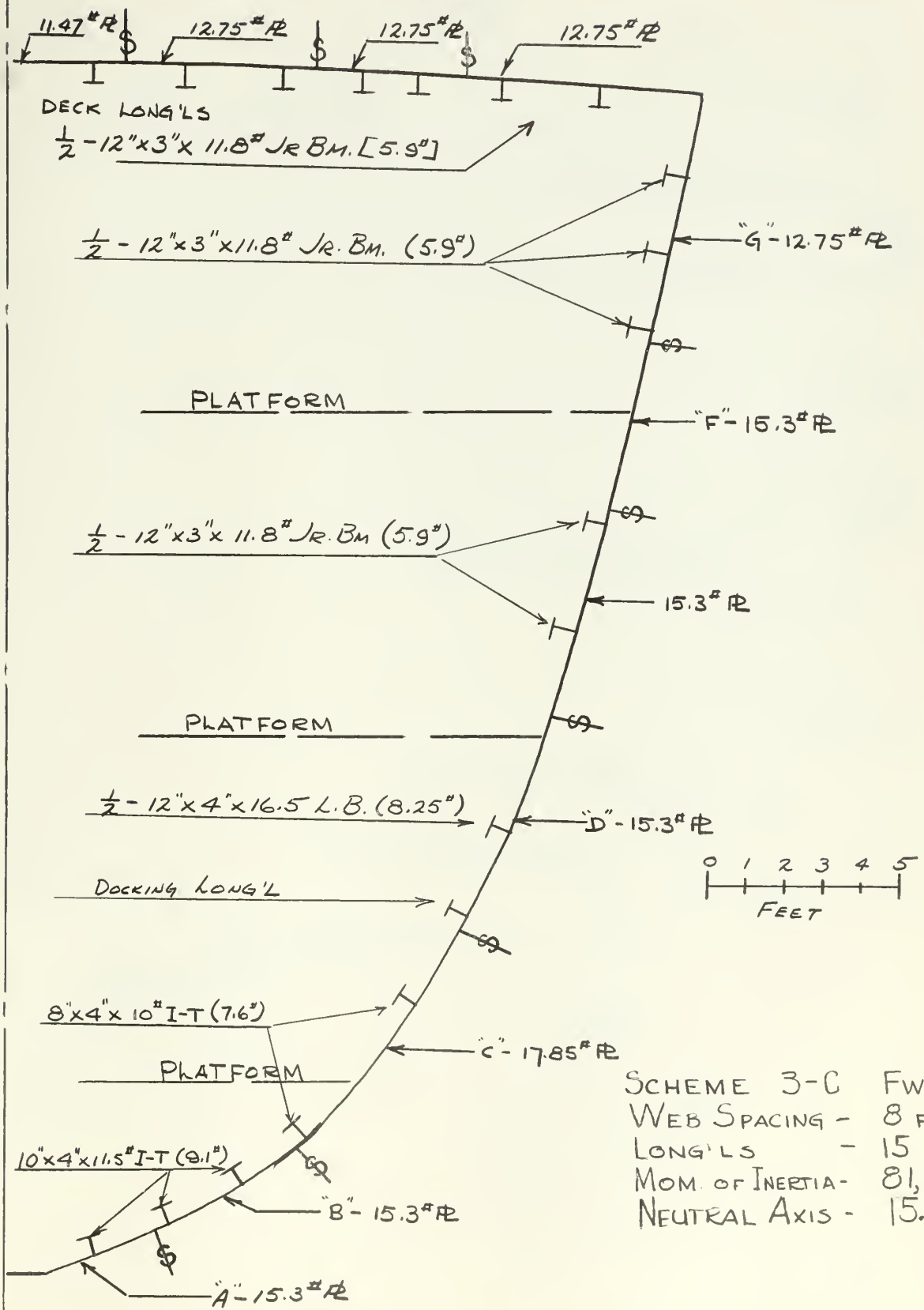
SCHEME 3B - XX
WEB SPACING - 9 FT.
15 LONGITUDINALS
NA - 12.39' ABOVE BL
I = 104,630 Ft^2 In^2

FIG. XXXII



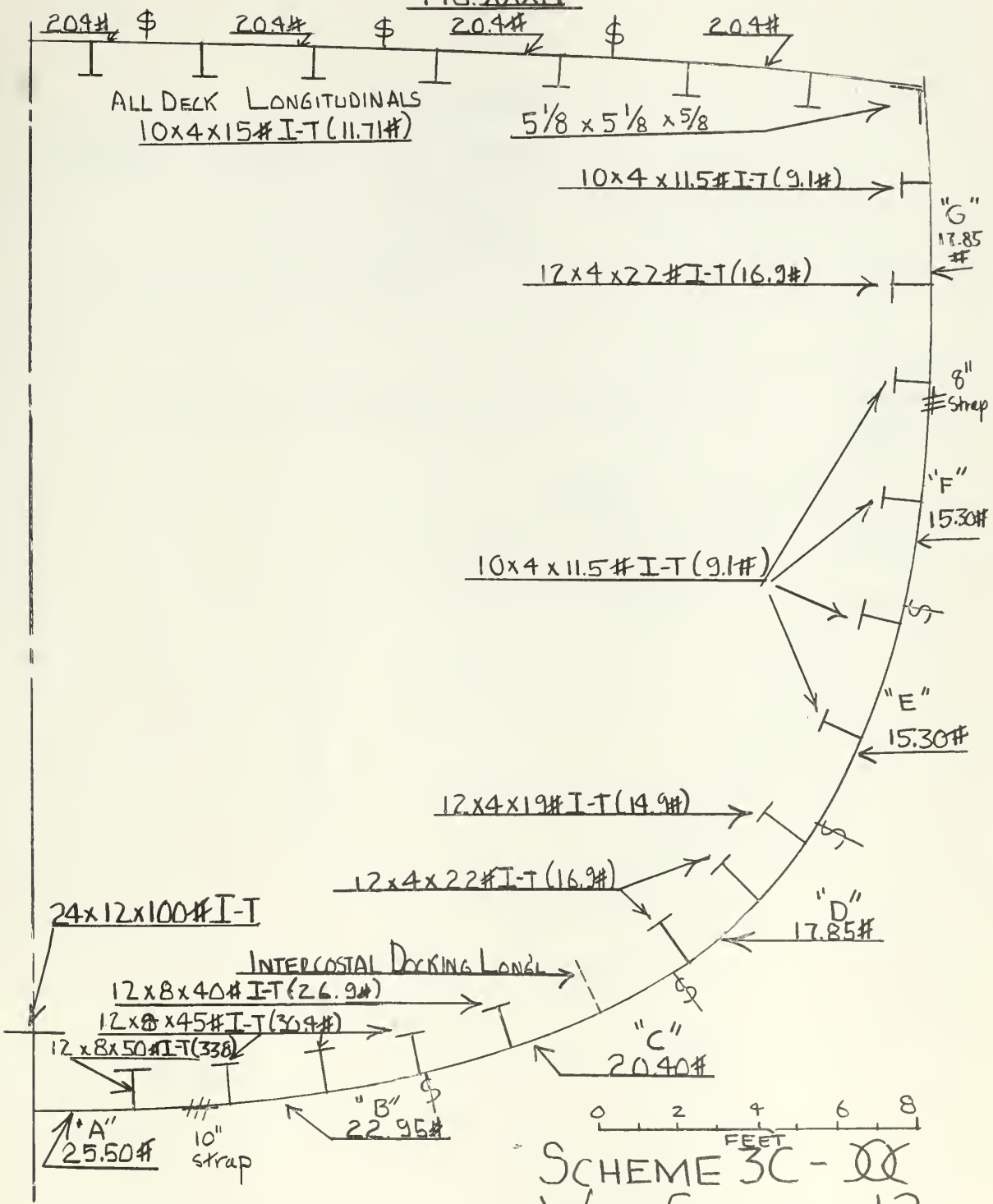
SCHEME 3B AFT
WEB SPACING 6.0FT.
15 LONGITUDINALS
NEUTRAL AXIS 14.44' ABOVE ℄
MOMENT OF INERTIA 43,567 FT²-□"

FIG. XXXIII



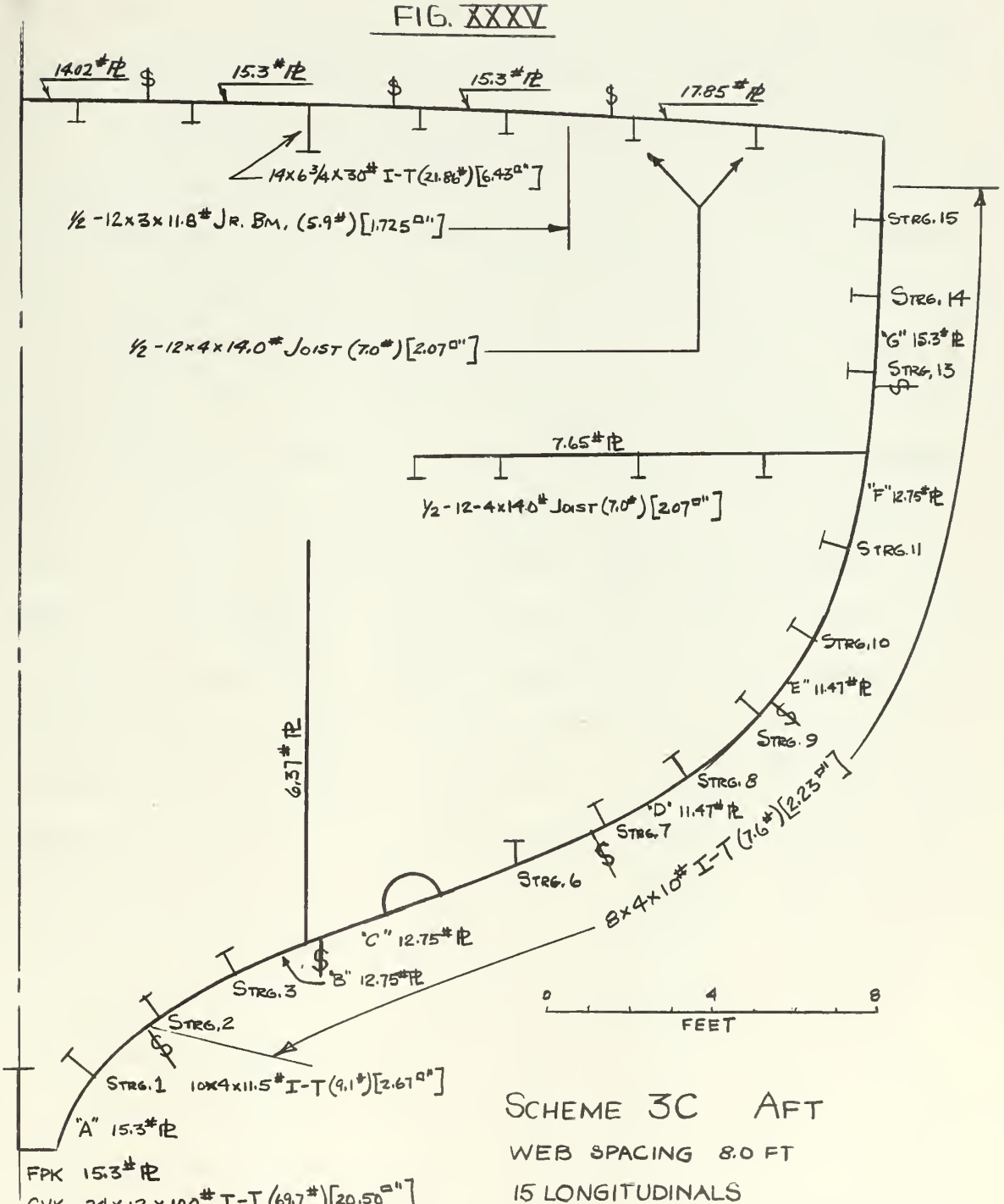
SCHEME 3-C FWD
WEB SPACING - 8 FT.
LONG'LS - 15
MOM. OF INERTIA - 81,484
NEUTRAL AXIS - 15.81 FT

FIG. XXXIV



SCHEME 3C - XX
WEB SPACING 12FT
15 LONGITUDINALS
N.A. - 12.58' ABOVE BL
$I = 106,933\ ft^2\ in^2$

FIG. XXXV



SCHEME 3C AFT

WEB SPACING 8.0 FT

15 LONGITUDINALS
NEUTRAL AXIS 14.46' ABOVE ℄
MOMENT OF INERTIA 44,016 Ft²-□"

APPENDIX C

Discussion of Alternate Method of Spacing Longitudinals

The assumption of a fixed ratio, greater than unity, between the spacing of longitudinals at the neutral axis and the spacing at the top and bottom of the ship girder flange, was based on nothing more than a suspicion that the longitudinals would thereby contribute more to the moment of inertia of the section than they would with an even spacing. As mentioned in the procedure section, however, it was realized that there might possibly be an advantage in plate distribution by use of the reverse ratio. To investigate this possibility, a cross section was laid out with the reverse ratio, all other criteria remaining constant, for the 12 longitudinal scheme with 8', 10' and 12' web spacings. A group of graduate students studying the basic method of midship section design which was used in this study, determined the scantlings and weight per foot of longitudinal material for each of these alternate schemes. Their calculations were not in all respects comparable with those in this investigation, but a study of their scantlings indicates that the difference in weight is very small, being less than 1%, more or less than the weights calculated in this study. Thus, there appears to be no overall advantage in either a closer or a wider spacing of longitudinals at the neutral axis compared to the rest of the girth, at least in the range of the small ratio of space variation used in these studies (this ratio was 1.17:1).

Nevertheless, there appears to be an advantage in

using the neutral axis as a starting point in the design procedure. The plating at the neutral axis is limited by local considerations since it is normally close to the water line and subjected to unpredictable loadings in docking, excessive corrossion due to alternate wetting and drying, and other conditions peculiar to the center of the web of the ship girder. It would therefore seem logical to determine the minimum acceptable thickness of the plating at the neutral axis on the basis of local loadings and then determine the maximum allowable stiffener spacing based on instability at the quarter points. Then the remaining number of stiffeners could be equally spaced about the remaining girth. In most cases this procedure will result in a wider spacing at the neutral axis than elsewhere, substantiating the assumption made in this investigation.

APPENDIX D - BIBLIOGRAPHY

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9. TURNBULL, J., "Longitudinal Strength - A Review of Some Recent Developments" - Transactions of the Institution of Naval Architects, 1953.

10. ST. DENIS, M., "On the Structural Design of the Midship Section" - DTMB Report C-555.

11. SHANLEY, F. R., "Weight-Strength Analysis of Aircraft Structures" New York, 1952.

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